

Conceptual Questions

CQ13. Yes. Motion with constant velocity.

CQ15. (a.) No. If air resistance can be neglected, then the acceleration of the ball is **constant** and equal to 9.81 m/s^2 downward the entire time it is in flight.

(b.) No. Same reason as in (a.).

Problems

3. (a.) The distance traveled by the ball is the sum of the distances traveled in the first putt and the second putt:

$$\text{distance traveled} = 12.5 \text{ m} + 2.5 \text{ m} = 15.0 \text{ m} .$$

(b.) The displacement of the ball is:

$$\Delta x = x_f - x_i = 10 \text{ m} - 0 \text{ m} = 10 \text{ m} ,$$

in which I took the starting point of the ball to be at 0 m.

9. (a.) Average speed = $\frac{\text{total distance}}{\text{total time}}$. If the kangaroo hops at a *constant* speed of 65 km/h, then its average

speed will be 65 km/h, so in 3.2 min it can hop a distance:

$$\text{total distance} = (65 \text{ km/h})(3.2 \text{ min}) = (65 \text{ km/h})\left(\frac{3.2}{60} \text{ h}\right) = 3.5 \text{ km} .$$

(b.) $\text{total time} = \frac{\text{total distance}}{\text{average speed}} = \frac{0.25 \text{ km}}{65 \text{ km/h}} = 0.0038 \text{ h} = 14 \text{ s}$

21. Velocity is the slope of the position-vs-time graph. So the sign of the velocity is as follows:

(a.) positive

(b.) zero

(c.) positive

(d.) negative

Average velocity for each segment is the slope of that segment. So using the endpoints of each line segment to get the slope, I get:

(e.) $v_{av} = \frac{\Delta x}{\Delta t} = \frac{2 \text{ m} - 0 \text{ m}}{1 \text{ s} - 0 \text{ s}} = 2 \text{ m/s}$

(f.) $v_{av} = \frac{2 \text{ m} - 2 \text{ m}}{2 \text{ s} - 1 \text{ s}} = 0 \text{ m/s}$

(g.) $v_{av} = \frac{3 \text{ m} - 2 \text{ m}}{3 \text{ s} - 2 \text{ s}} = 1 \text{ m/s}$

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$$(h.) \quad v_{av} = \frac{0 \text{ m} - 3 \text{ m}}{5 \text{ s} - 3 \text{ s}} = -1.5 \text{ m/s}$$

31. (a.) If the acceleration is *constant* at 1.30 m/s^2 due north, then there is no difference between instantaneous acceleration and the average acceleration. So we can write:

$$a = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{\Delta t} .$$

Solving for v_f gives:

$$v_f = v_i + a\Delta t .$$

So after a time interval Δt of 7.50 s, the velocity will be:

$$v_f = 18.1 \text{ m/s} + (1.30 \text{ m/s}^2)(7.50 \text{ s}) = 27.9 \text{ m/s}$$

- (b.) If the acceleration is again constant but now 1.15 m/s^2 *due south*, then the acceleration should be given a minus sign (since the initial velocity, which was in the direction of *due north*, was *positive* 18.1 m/s). So we have:

$$v_f = v_i + a\Delta t$$

$$v_f = 18.1 \text{ m/s} + (-1.15 \text{ m/s}^2)(7.50 \text{ s}) = 9.48 \text{ m/s} .$$

45.
$$a_{av} = \frac{\Delta v}{\Delta t} = \frac{45 \text{ m/h}}{2.2 \text{ s}}$$

At this point we must be careful because we've got two different units for time. In order to get a consistent set of units for the time, I'll convert 2.2 s to hours and write:

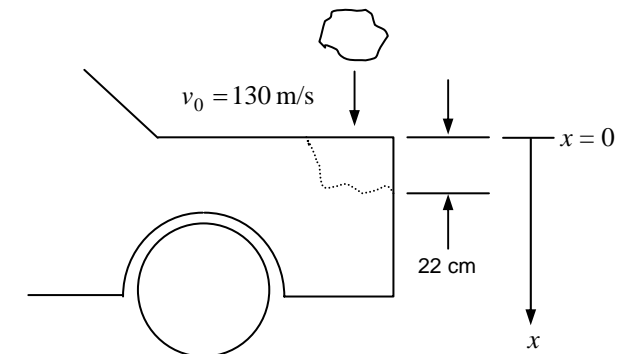
$$a_{av} = \frac{45 \text{ m/h}}{\left(\frac{2.2}{3600} \text{ h}\right)} = 73636.36 \text{ mi/h}^2 .$$

Now these probably aren't the most convenient units to give the acceleration in, since the motion takes place in a small fraction of an hour (maybe a few seconds). It might be more useful to give the acceleration in m/s^2 , so I'll convert:

$$\left(\frac{73636.36 \text{ mi}}{\text{h}^2}\right) \left(\frac{1 \text{ h}}{3600 \text{ s}}\right)^2 \left(\frac{5280 \text{ ft}}{1 \text{ mi}}\right) \left(\frac{12 \text{ in}}{1 \text{ ft}}\right) \left(\frac{2.54 \text{ cm}}{1 \text{ in}}\right) \left(\frac{1 \text{ m}}{100 \text{ cm}}\right) = 9.1 \text{ m/s}^2 .$$

Note that the second conversion factor above must be squared in order to cancel the units h^2 which occur in the denominator in 73636.36 mi/h^2 . Note also that I waited until the very end of the calculation to round off to the proper number of significant figures (two sig figs). I did this to minimize round-off error. If I had rounded 73636.36 mi/h^2 to the correct number of sig figs before I started the unit conversion, it might have made the round-off error in the final answer worse.

50. Let's draw a picture of the situation:



The meteorite goes from a velocity of 130 m/s downward to a velocity of zero m/s in a distance of 22 cm. So I know the velocity at two times: $t = 0$ (when the deceleration begins) and the time t at which the meteorite stops (when its velocity goes to zero). I also know the *position* of the meteorite at these two times: If I take the initial position (just before the meteorite hits the car) to be $x = 0$ and the positive direction for x to be downward, then the meteorite's position when it comes to rest will be $x = 22$ cm. (Refer to the picture.) Assuming the magnitude of the deceleration to be *constant*, I can apply any of the four equations for motion in one dimension with constant acceleration. In particular, I figure I can get the acceleration from:

$$v^2 = v_0^2 + 2a(x - x_0).$$

Solving for a and plugging in numbers gives:

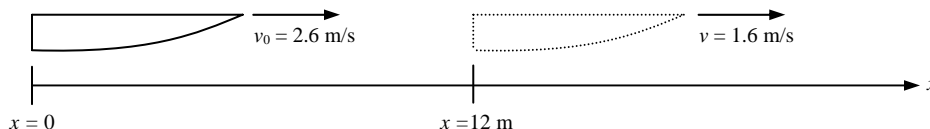
$$a = \frac{(v^2 - v_0^2)}{2(x - x_0)} = \frac{-(130 \text{ m/s})^2}{2(0.22 \text{ m})},$$

in which I've expressed 22 cm in *meters* in order to keep the units for length consistent. So

$$a = -3.8 \times 10^4 \text{ m/s}^2,$$

keeping two significant figures. So the magnitude of the deceleration is $3.8 \times 10^4 \text{ m/s}^2$.

57. (a) The boat was moving at a constant speed of 2.6 m/s until it was shifted into neutral. When it was shifted into neutral, it began decelerating. It continued decelerating for a distance of 12 m. At the instant when it had been decelerating for a distance of 12 m, the speed had been reduced to 1.6 m/s. Here's a picture of the situation, with an x axis chosen as shown:



Because the acceleration was constant, we can use any of the equations for motion with constant acceleration. I want to know, "What is t when $x = 12$ m?" (Note that t is understood to be zero when the deceleration begins, i.e., when $x = 0$.) Well, I figure I can find the answer from:

$$x = x_0 + \frac{1}{2}(v_0 + v)t = \frac{1}{2}(v_0 + v)t.$$

Solving for t gives:

$$t = \frac{2x}{v_0 + v} = \frac{2(12 \text{ m})}{4.2 \text{ m/s}} = 5.7 \text{ s},$$

keeping 2 significant figures.

(b.)

$$v^2 = v_0^2 + 2a(x - x_0)$$

$$a = \frac{v^2 - v_0^2}{2x} = \frac{(1.6 \text{ m/s})^2 - (2.6 \text{ m/s})^2}{2(12 \text{ m})} = -0.175 \text{ m/s}^2$$

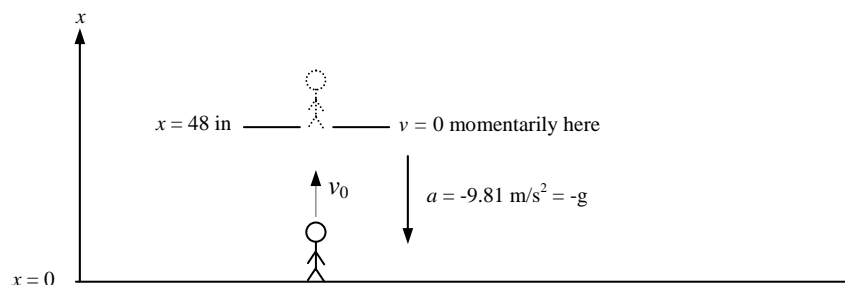
(c.)

$$v^2 = v_0^2 + 2a(x - x_0)$$

$$v = \sqrt{(2.6 \text{ m/s})^2 + 2(-0.175 \text{ m/s}^2)(6.0 \text{ m})}$$

$$v = 2.2 \text{ m/s}.$$

67. The situation is pictured (although admittedly very crudely) below. I've chosen the positive x direction to be upward because it seems natural to let MJ's velocity on the way up be positive. A consequence of this choice, though, is that MJ's *acceleration* – the free-fall acceleration – is *negative* 9.81 m/s^2 , or $-g$, as noted in the picture.



We know the following:

- $x_0 = 0$ (by choice)
- $v = 0$ when $x = 48 \text{ in}$ (= 1.2192 m, doing a unit conversion)
- $a = -g$

And we want v_0 . Well, according to one of the free-fall equations:

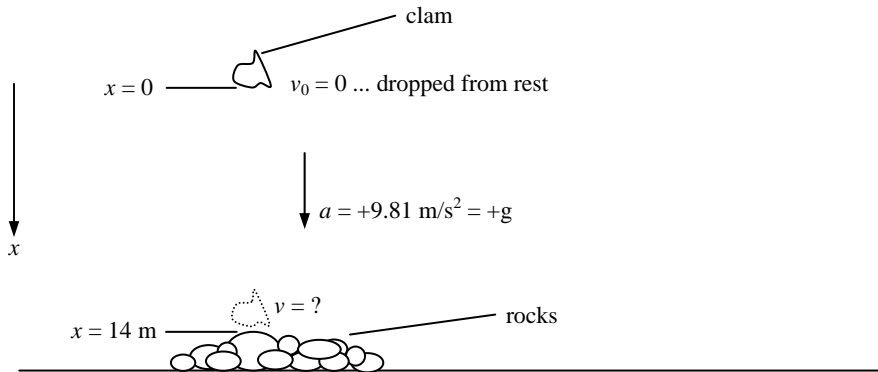
$$v^2 = v_0^2 - 2g(x - x_0).$$

Plugging in numbers that I know: $0 = v_0^2 - 2(9.81 \text{ m/s}^2)(1.2192 \text{ m})$,

which gives:

$$v_0 = 4.9 \text{ m/s}.$$

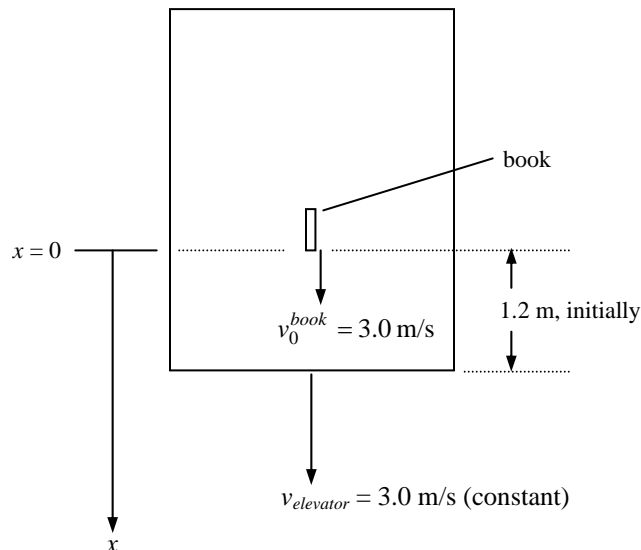
68. Picture:



I've chosen the positive direction for x to be downward here because that is the way the clam is actually going to move. (By the way, this is a pretty good general rule of thumb to use in choosing the positive direction. It tends to minimize the number of minus signs that you have to deal with.) With this choice, the acceleration is *positive* 9.81 m/s^2 , as shown. From the free-fall equations, I find:

$$\begin{aligned}
 v^2 &= v_0^2 + 2g(x - x_0) \\
 &= 2gx \quad (\text{putting in initial conditions}) \\
 \text{So } v &= \sqrt{2gx} = \sqrt{2(9.81 \text{ m/s}^2)(14 \text{ m})} \\
 v &= 17 \text{ m/s}.
 \end{aligned}$$

80. A picture of the situation is shown below. The positive direction for x has been chosen to be downward and $x = 0$ has been taken to be the position of the lower edge of the book at the instant it is released. At the instant the book is released, the elevator *and the book* (and everything else in the elevator) are going downward at a constant speed of 3.0 m/s . The elevator continues to move downward at 3.0 m/s the entire time the book is falling.



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- (a.) Since the elevator moves with constant velocity, there is no difference between its velocity at any *instant* and its *average* velocity for any time interval Δt . Therefore, for the elevator:

$$3.0 \text{ m/s} = \frac{\Delta x}{\Delta t} = \frac{x - x_0}{t},$$

in which I've taken t_0 to be zero. From this equation, the position of the *floor* of the elevator is given by:

$$x = x_0 + (3.0 \text{ m/s})t = 1.2 \text{ m} + (3.0 \text{ m/s})t. \quad (1)$$

Now let's figure out how to write an equation for the position of the lower edge of the book. Once the book is released, it's in free-fall, so we can apply any of the facts we know about for objects in free-fall. In particular, we know:

$$x = x_0 + v_0 t + \frac{1}{2} g t^2$$

For the lower edge of the book, this becomes:

$$x = (3.0 \text{ m/s})t + \frac{1}{2} g t^2 \quad (2)$$

Setting the right-hand sides of Equations (1) and (2) equal to one another allows us to solve for the time when the position of the lower edge of the book equals the position of the floor of the elevator (i.e., when the book hits the elevator floor):

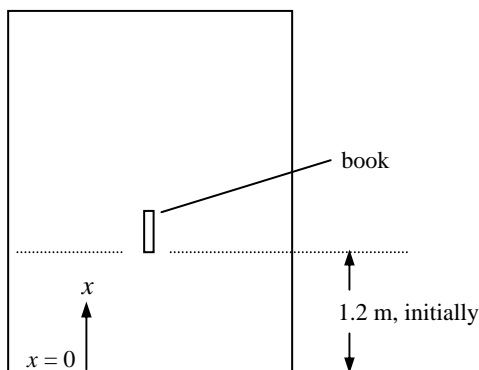
$$(3.0 \text{ m/s})t + \frac{1}{2} g t^2 = 1.2 \text{ m} + (3.0 \text{ m/s})t.$$

Notice that the term $(3.0 \text{ m/s})t$ appears on each side of the equation above. So it cancels, and we have:

$$\begin{aligned} \frac{1}{2} g t^2 &= 1.2 \text{ m} \\ t &= \sqrt{\frac{2(1.2 \text{ m})}{g}} \\ t &= 0.49 \text{ s.} \end{aligned}$$

This is the time when the book hits the elevator floor.

There's deep significance in the fact that the speed of the elevator, 3.0 m/s, didn't enter into the final result for t . Apparently the fact that the elevator is moving downward at 3.0 m/s has no bearing at all on the time required for the book to fall to the floor of the elevator! This is very much related to the idea of what is called an **inertial reference frame**, or just an **inertial frame**. An inertial frame is any "frame of reference" – any coordinate system – that is either *fixed* (not moving at all) or *moving with constant velocity relative to a fixed frame*. It turns out that the laws of physics – the equations that determine things like the position of an object at some time t – have the same form *in any inertial frame*! In the solution above, we chose a coordinate system whose origin was assumed (without explicitly saying so) to be *fixed*, while the book and the elevator moved. Now suppose instead that we chose a coordinate system that *moved with the elevator*. This might be accomplished by taking the origin – the place where $x = 0$ – to be the floor of the elevator, as shown below:



Now as the elevator descends at a constant speed of 3.0 m/s (relative to the earth) *it carries the coordinate system with it*, so that in this coordinate system, the position of the floor of the elevator is always $x = 0$. How would you describe the position of the lower edge of the book in this coordinate system? Well, in this coordinate system, the initial velocity of the book is zero. (It's moving with the elevator, initially.) So our equation that describes the position of the book once it goes into free-fall becomes:

$$x = x_0 + v_0 t - \frac{1}{2} g t^2 = 1.2 \text{ m} + 0 - \frac{1}{2} g t^2$$

Notice that the acceleration appears as $-g$ because the positive direction for x has been chosen to be upward.

In *this* coordinate system, the question, "When does the book hit the elevator floor?" is the same as the question, "What is t when the position of the book equals zero?" So we set x equal to zero in the equation above and solve for t , and we get:

$$0 = 1.2 \text{ m} - \frac{1}{2} g t^2$$

$$t = \sqrt{\frac{2(1.2 \text{ m})}{g}}$$

Notice that this is exactly the same expression we got for t with the original choice of coordinate system! So once again we get $t = 0.49 \text{ s}$.

- (b.) If I want to find the velocity of the book as seen by a person standing *in the elevator*, I want to use the second reference frame chosen in Part (a.). In this reference frame, I have:

$$v = v_0 - g t = 0 \text{ m/s} - (9.81 \text{ m/s}^2)(0.49 \text{ s})$$

$$v = -4.8 \text{ m/s},$$

so the *speed* (the *magnitude* of the velocity) is just 4.8 m/s.