# Chapter 2 - Motion Along a Straight Line

## Physics 206

For any problems where you are given a variable/symbol and a value for that variable, make sure to solve the problem symbolically first. Your final answer should then only contain the variables that you are given values for in the problem, constants that appear on the equation sheet and numbers like 2 or $\pi$.

**Group 1 Problems:**

**Problem 1** Two cars are traveling in the $x$-direction. At $t = 0$, car 1 is at position $x = -200$ and has a constant velocity of $v = +60$. At $t = 0$ car 2 has a position of $x = +200$. What time or times are the cars at the same position if:
a) At $t = 0$, car 2 has a velocity of $v = +5$ and an acceleration of $+2$.
b) At $t = 0$, car 2 has a velocity of $v = +10$ and an acceleration of $+5$.
c) At $t = 0$, car 2 has a velocity of $v = -5$ and an acceleration of $-2$.

**Problem 2** Two police officers are separated by a distance of 1 kilometer to set up a speed trap on a road. The speed limit on this road is 60 kilometers per hour.
a) A car passes the first officer going 55 kilometers per hour at $t_0 = 0$ and passes the second officer going the same speed at $t = 60$ seconds. Assuming that the car can't instantly accelerate to difference speeds, did the driver speed at any point? Why? Note: it is not necessary to find the exact maximum speed.
b) How long would the driver need to take to convince the police officer that no speeding happened and that they were driving a constant 55 km/hr?
c) Even if the driver took the time determined in part b), does that necessarily mean the driver never speed? What could have happened (even if contrived)?

**Problem 3** A person is standing at the 3rd floor window in an apartment building, a height 15 m above the ground. At $t = 0$, they see a baseball traveling straight upward at 10 m/s. At what time was the baseball thrown up from the ground? At what speed was the baseball thrown upward? What will be the total length of time the ball is in the air?

**Problem 4** A frog is perched on a lily pad awaiting a snack. After a short wait, the frog notices a fly 0.15 meters away. The frog's tongue flies through the air with an acceleration function:

$$a(t) = 100 - t^2$$

a) Find $v(t)$ and $x(t)$ of the frog's tongue.
b) If the fly has a reaction time of 0.050 s, will the frog get his snack?

**Problem 5** Consider the motion of a particle that experiences a variable acceleration given by $a_x = 2 + 6t$. You know that at $t = 2$ the velocity is $v(2) = 4$ and at $t = -3$ the position is $x(-3) = 22$.
a) Find the formulae for the velocity and position of this object as a function of time.
b) What is the average velocity of this object between $t = 0$ and $t = 5$? What is the difference between this and the average of $v(0)$ and $v(5)$?
c) What is the average acceleration of this object between $t = 0$ and $t = 5$? What is the difference between this and the average of $a(0)$ and $a(5)$?
d) Why is the answer to part c zero, but the answer to part b is not?

**Group 2 Problems:**

**Problem 6** Blythe and Geoff compete in a 1-km race. Blythe's strategy is to run the first 600 m of the race at a constant speed of 4 m/s and then accelerate with constant acceleration to her maximum speed of 7.5 m/s which takes her 1 min, and then finish the race at that speed. Geoff decides to accelerate with constant acceleration to his maximum speed of 8 m/s at the start of the race and to maintain that speed throughout the rest of the race. It takes Geoff 3 min to reach his maximum speed. Who wins the race?

**Problem 7** A ball is dropped from an initial height $y_0$ to the ground at $y = 0$. It takes 2 seconds for the object to fall from $y_0/2$ to the ground. How much time did it take to reach $y_0/2$? What was the initial height of the ball? What was the velocity of the object at $y_0/2$ and when it hit the ground?

**Problem 8** In each of the following you will be given a formula for either $x(t)$, $v(t)$ or $a(t)$ and be asked to find some information about at least one of the others.
a) What is $v(t)$ and $a(t)$ given:

$$x(t) = \frac{1}{2}t^2 + t + 1$$

b) At what time(s) is the velocity zero, given:

$$x(t) = t^4 - 3t^3 + t^2 + 1$$

c) What is the shape of the acceleration function in part b)?
d) You know an object's velocity function is given by the formula below. What more information do you need in order to find the displacement of the object between two times? What about to find the position at any time?

$$v(t) = 5t + 2$$

**Problem 9** A speeder is racing down the highway at 105 mi/hr. The speeder passes a state trooper who is at rest behind a road sign. The trooper takes two seconds after the speeder passes to start moving and accelerates at a constant 20 mi/(hr·s). Assume the speeder maintains a constant speed and the trooper accelerates at this constant rate.
a) How long does it take for the trooper to catch up to the speeder?
b) How far has the speeder traveled in that time?
c) How fast is the trooper going when he catches up to the speeder?
d) Are the assumptions of the speeder at constant speed and trooper at constant acceleration reasonable? Why or why not?

**Problem 10** A bottle rocket is launched from rest vertically with a constant acceleration of 5.00 $m/s^2$. The reaction stops after 8.00 s. What is the maximum height the bottle rocket reaches?

**Group 3 Problems:**

**Problem 11** During a science fair, there is a classic egg drop competition. Eggs are dropped (with no initial velocity) from a bridge that is height $H$ above a dry creek (which would, in turn, have height 0). It is up to the students to design a system to safely deliver the eggs to the bottom. Student A, B, and C all use somewhat similar designs involving strings taped to the egg and tied to a grocery bag parachute (budget cuts). Student A must have made quite an error in this setup because as soon as the egg is dropped the strings detach and the egg enters freefall to the ground. Student B did marginally better; while the parachute was working, the egg had an acceleration half that of gravity. However, halfway down (at height $H/2$), the strings also detach, rendering the parachute ineffective. Student C did the best. Their parachute stayed on the entire time, maintaining that acceleration half of gravity for the entire duration of its trip.
a) How long does it take each egg to hit the ground?
b) If the students wanted the eggs to hit the ground at the same time, from what different heights would each need to be dropped from? Assume that egg B still has its parachute fall off at half its initial height. Solve for $H_A$ and $H_B$ in terms of $H_C$.

**Problem 12** You are designing a straight track for drag racing. You know that your car has a higher top speed than everyone else, but a slower acceleration rate. If you can reach a max acceleration of 12 $m/s^2$ and a top speed of 220 mi/hr, but everyone else can accelerate at 14 $m/s^2$ and have a top speed of 200 mi/hr, what minimum length of track is necessary for you to build in order to ensure you always win your races? What if you know that you are a half-second slower in reacting to the green light to start racing – how does that affect your ideal track length?

**Problem 13** Dave and Alex are playing with confetti eggs. Dave is standing still and Alex is biking from 30 meters away towards Dave with a velocity function

$$v(t) = \frac{4}{3}t + 5.$$

When Alex is 20 meters away they throw an egg at Dave that flies through the air with an acceleration function

$$a(t) = 10 - 8t.$$

Dave can dodge the egg if they have at least 1.8 seconds. Does Dave get hit by the egg?

**Problem 14**: A student is running with a constant speed of $v_s$ to catch a bus, which is stopped at the bus stop. When the student is still a distance $d$ from the bus, it starts to pull away, moving with a constant acceleration of $a_b$.
a) How much time after the bus begins to move does it take the student to catch the bus? How far did they run during this time?
b) When the student first reaches the bus, how fast is the bus traveling?
c) Sketch an $x$ vs $t$ graph for both the student and the bus using the same axes. Take $x = 0$ as the initial position of the student and $t = 0$ as the time the bus begins to move.
d) If part a) was solved correctly, there were two mathematically correct times that you found but only one was physically correct given the conditions of the problem. What did the second solution physically correspond to?
e) There exists a minimum speed $v_{min}$ that the student can have so that they just catch the bus and never pass it. What is this minimum speed and what is the time and distance they have to run in order to catch the bus?

**Problem 15**: In *The Fellowship of the Ring*, the hobbit Peregrine Took (Pippin for short) drops a rock into a well while the travelers are in the caves of Moria. This wakes a balrog (a bad thing) and causes all kinds of trouble. Pippin heard the rock hit the water 7.50 s after he dropped it.
a) Ignoring the time it took the sound to get back up, how deep is the well?
b) If the speed of sound is 340 m/s (it was pretty cool in that part of Moria), was it reasonable to ignore the time it takes the sound to get back up? Discuss and support your answer with a calculation.