Physics 101 Lecture 2

Please turn in homework now!

Physics, especially introductory courses, is a problem-solving science. You have some hypothesis or question and you want to know the answer or if Nature works as you expect it to. As a professional, card-carrying physicist, how do I know that my solution to a problem is correct? In general, I don't, but if other people independently check it, I gain confidence in its veracity. However, There are numerous tricks that a physicist has in the bag that we carry everywhere to check if a potential answer is wrong or can't possibly be correct. Throughout the semester, I'll let you in on the secrets of the trade and today we'll introduce the most powerful of all of them: dimensional analysis

What makes dimensional analysis so powerful is noting that everything we can possibly measure has specific units. In this course (and much of physics) we use the SI unit system in which measured quantities are expressed in terms of the fundamental length (meter), time (second), and mass (kilogram). Every quantity we will discuss in this class is some combination of these basic units.

For example, let's say you want to determine your speed in running 100 meters. Speed is the amount of distance you travel per unit time. We will often write speed as the letter v and we can denote its units by writing:

$$[v] = \frac{\text{meters}}{\text{time}}$$

Given that you ran 100 meters, to determine your speed all you need to do is divide by the time it took to run it. If you are very fast, it might take you 10 seconds to run 100 meters. Therefore your speed would be

$$V = \frac{100}{10} \frac{\text{meters}}{\text{second}} = 10\ \text{m/s}$$

We can convert this into units you may be more familiar with. Let's express m/s in miles/hour. We can do this by multiplying by "1" in particular ways.

For example: $1\ \text{meter} = 1\ \text{meter} \cdot \frac{1\ \text{mile}}{1\ \text{mile}} = \frac{1\ \text{meter}}{1\ \text{mile}} \cdot 1\ \text{mile}$

$$= \frac{1}{1609} \cdot 1\ \text{mile}$$

The factor $\frac{1}{1609}$ is (approximately) the number of miles that you can cram into a meter. This is (much!) less than 1 because a mile is longer than a meter.

What about seconds? Let's convert 1 second into an hour:

$$1\ \text{second} = 1\ \text{second}\ \frac{1\ \text{hour}}{1\ \text{hour}} = \frac{1\ \text{second}}{1\ \text{hour}} \cdot 1\ \text{hour} = \frac{1}{3600}\ 1\ \text{hour.}$$

There are 3600 seconds in an hour. Now, we can convert meters/second to miles/hour:

$$\frac{\text{meters}}{\text{second}} = \frac{1}{1609} \cdot 1\ \text{mile} \cdot \frac{3600}{1\ \text{hour}} = 2.2\ \frac{\text{miles}}{\text{hour}}$$

So, if you ran 100 meters in 10 seconds, your speed was 10 m/s or about 22 mph.

This is an example of how dimensional analysis works. We first identify the quantity we want to calculate; in this case, a speed. Speed has units of distance over time, so to evaluate the speed we need to measure both a distance (say, 100 meters) and a time (say, 10 seconds). Dimensional analysis is the trick/shortcut/tool to get to an estimate of the answer simply by ensuring that the expression has the right units (dimension).

Thus, dimensional analysis is very helpful for telling you that an answer cannot possibly be correct. If the units of an expression are not correct then the answer cannot be correct.

Let's see how this works in an example. Say we want to determine a distance, d. We are given/measure quantities of time t, velocity/speed v, and acceleration a (units m/s^2), which of the following cannot be correct?

a) $d = at$ b) $d = mvt$ c) $d = v/t$ d) $d = v^2/a$

Discuss with your neighbors! I'll give you a minute.

What did you find? Note that the quantity "at" has units of m/s, not a distance. Also, "mvt" has mass in it, which is not a distance. "v/t" has units of m/s^2, which is acceleration. So, all of a), b), and c) cannot be the expression for distance. d) on the other hand does have the correct units:

$$\frac{v^2}{a} = \left(\frac{m}{s}\right)^2 \frac{s^2}{m} = m \checkmark$$

We'll revisit dimensional analysis as an important tool throughout the semester.

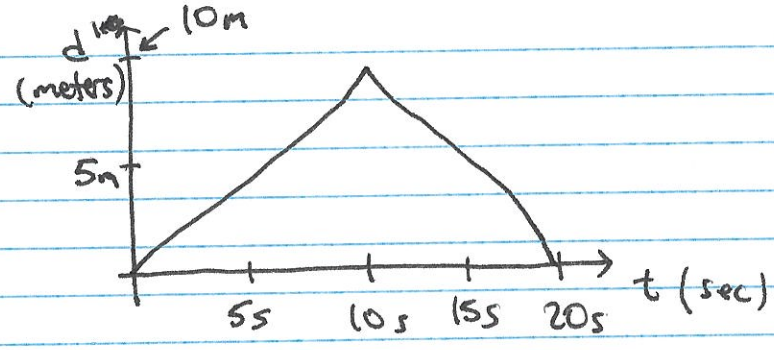
For now, let's get into understanding and modeling physical systems. Physics is the study of how and why objects in the natural world change in time. We'll start this topic, of how to model objects changing, small and expand our purview in the course of the semester. ~~For now, we will simply consider~~

So, what's the simplest way that an object ~~ca~~ can change in time? I'm exhibiting it right now: an object can keep its shape and substance the ~~sam~~ same and just <u>move</u> through space. We live in a universe with three spatial dimensions, so ultimately we need to know how to understand motion in many dimensions. With our principle of starting small, let's ignore two of the dimensions; that is, we are just considering motion along a line. For many systems, this is very reasonable. For example, a train moves one direction along linear tracks, so we can (often) ignore lateral motion to the tracks or motion up and down. One-dimensional motion is what I am doing at the front of class: just pacing back and forth.

If we want to be quantitative and model my motion as a function of time, there are a few things we need to address. First, how do we measure this motion? We already agreed that we use SI units so we measure the distance I travel in meters and the time over which I traveled in seconds.

The next thing we need to do is to determine <u>when</u> to start the time and <u>where</u> to measure distances from. In a race, both of these things are unambiguous: the clock starts with the gun, and distances are measured from the starting line. For my pacing, it's less clear when to do either. This is not an accident: in the natural world there is no "preferred" initial time or position. We have to impose both to be able to meaningfully speak about some physical process.

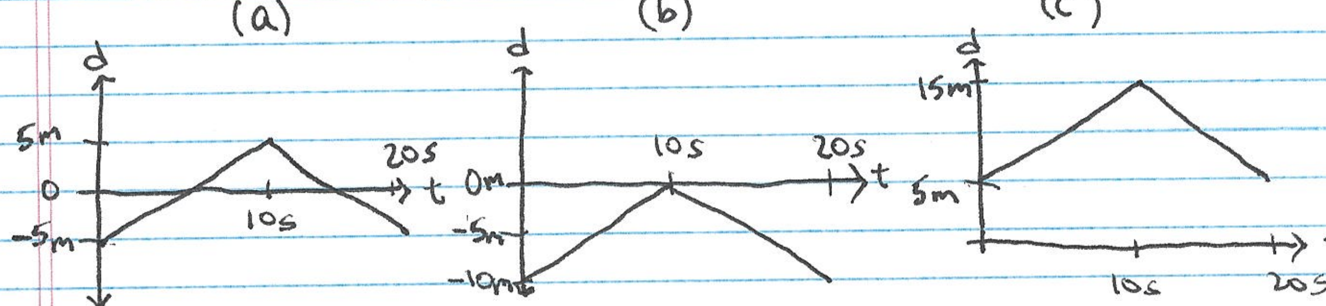
With that in mind, let's attempt to model my pacing from one side of the well to the other, and back. We will start the clock when I leave one side and also measure distances from where I start. With this agreement we can draw a graph of my position in the well as a function of time:



Here, I have assumed that the well is 10 meters across and it takes me 20 seconds to walk out and return. This plot shows that as I just set out I am getting farther from the origin; my distance is increasing. At 10 s, the increasing switches to decreasing distance, meaning I am getting closer to the origin as time inceseases; I have turned around.

Note also that I have represented distances with positive numbers (5 m, e.g.). It is easy to represent the direction of my relationship to the origin: just use positive or negative numbers. ~~We'll agree that~~ Distances that account for relative relationships of location to an origin are displacements. We'll agree that positive displacements are to your right, while negative displacements are to the left of the origin.

With that in mind, I have another question! Consider again my walk across and back in the well. Three graphs of my motion are shown below. Can you determine where the spatial origin is for each? Talk to your neighbors!



Okay, back to it! For (a), I have moved the origin to the center of the well. I start to the left of center (origin), move past it, then turn around. For (b), the origin is now at the opposite wall, and I only get to position 0 at my turning point. For (c), I've moved the origin 5 m to the left of where I start walking! I guess it would be near the Blue Bridge.

We're about done for today, but I want to emphasize something extremely important. I've drawn four different graphs to represent me walking from one side of the room to the other. What I did was identical; we just represented ~~it~~ it in several ways. Our particular way to describe the natural world is arbitrary and irrelevant; it does <u>not</u> affect what is actually happening. This is important to remember: drawing figures and graphs is very powerful for gaining understanding, but we have to remember that the drawing represents Nature, and not vice-versa.

Have a good weekend!