Intro and Units

1. About physics

It may seem like physics is here to make your lives harder. However, one of our prime motivations in this class will be to see how physics actually makes things easier.

You'll hear a lot of different answers to the question: *what is physics?* You can decide for yourselves as we go through this course.

2. Why Physics?

3. The goals of physics

- Predict *everything* (i.e. the future of the universe)
- If you can't, then isolate parts of the system until you can

A long time ago, the things people needed to predict might seem trivial to us now. For example, when the rainy season was going to come, when were the tides of the oceans the largest, how high of a tree can I fall out of without smashing my shinbones, essentially, basic survival. As we began to acquire the ability to modify our environment and create tools, then the things we needed to predict became somewhat more complicated: what angle should I fire this cannonball to make it hit that building over there, what shape should the tube on a pipe organ be to make it sound nice, how thick should the cables holding up a bridge platform be? Also, other questions regarding humans became interesting: does listening to Mozart as a baby make you smarter? If I smoke 40 cigarettes everyday, will that affect my future in any way? Are criminals born or made? Of course, some of these questions are currently understood, and predictable. Others are not at the moment. (and perhaps never will be)

Why is that the case? Why are some questions about the universe more tractable (solvable) than others? Some might say there are fundamental differences which make certain topics unpredictable. Others would say we just don't understand the universe well enough. Imagine a set of pool balls about to broken. If we knew exactly the velocity and position of every ball, and the cue ball, then we should be able to predict where they all end up after the break. Of course, this doesn't seem doable in real life. Tiny bumps in the surface of the table will change the direction of some balls. Defects in the surface of other balls will cause their collisions to be erratic. Maybe the wind from the ceiling fans will deflect some of them in weird ways. Yet, the burning intuition is that if we knew everyone one of these variables, then we could indeed predict the motion of all 16 balls after the break. (This is why no one likes playing pool with physicists.) So, in order to begin to figure this out, we would have to know how all the balls would move without the influence of these tiny variables. We then assume the table is perfectly flat.

Likewise, let's assume that all the balls are perfect spheres. And that there is no wind in the pool hall. Now, we've simplified the situation enough to allow us to figure out how the perfect balls on a perfect table would move. Then, we can begin introducing more little bits, like the friction of the table, the dings in the balls, etc. This is the grand scheme of most of physics for that few centuries: take the system apart enough to let us model it, then add the other, 'real world', bits back in. And that's what this course will do.

Navigating life is in some ways about learning what to ignore, and what to pay attention to. You notice children pointing out small things that seem to an adult trivial and inconsequential. They haven't learned yet how to separate the world into these categories, (and bless them for that). Likewise, you, as infant physicists, will have to learn what to ignore and what to pay attention to. That's half the battle.

The divisions of Physics ca. 2020

Classical	**Modern**
Mechanics	Quantum Physics
Electricity	Cosmology
Magnetism	Nuclear
Thermodynamics	
Fluids	Condensed Matter
Waves	Bio-Physics
Optics	

Physics has become an enormous scientific discipline. This course will cover most of the things in the classical physics column.

3.1 How do we do this?

The Scientific Method:

Question → hypothesis → testing → analysis

Physics: Division of Labor

Some physicists work on *theory*. Others do *experiments*. While they have different approaches to things, they basically agree on a few major points.

1. Theories must be verifiable by experiment
2. Phenomena can be described mathematically
3. Experiments must involve measurements

We've all heard about the 'scientific method' since high school if not before. While discussions about what exactly this is can be quite lengthy, we can adopt a straightforward definition for this course. Essentially, the scientific method sets a course of action for learning about the natural world. One idea for what wold make a valid scientific theory, we should be able to perform an experiment that could disprove it. For example, if I had a theory that said that based on what I know about water molecules, water should boil at 130 degrees C, this theory could be disproven by performing an experiment: measuring the boiling of water. If we found that water didn't boil at 130 C, but at some other temperature, then I'd have to readjust my theory. This is the scientific method in a (very small) nutshell. If however, I had a theory that said that aliens exist because the universe is so big that they just have to, then that's not really a theory we can disprove (without exploring the entire the universe, which is not even remotely feasible).

Each of the scientific disciplines operate in slightly different ways. The basic mechanism of physics as a science involves the perpetual exchange between 'theory' and 'experiment'. Some of us physicists find that we are better doing physics with our hands. We become experimentalists. Others are more facile with math and pencils, and they become theorists. The two camps work together, but independently. A theorist might come to an experimentalist and say, look, here's what my theory about water says the freezing point should be. Can you test this out? The experimentalist does and reports back. Or, maybe, during the experiments with water, the experimentalist notices something else happening to the water, like if you leave it boiling for very long, it all disappears. She then goes back to the theorist, and asks, hey, look what happened when I left the water boiling all day - it disappeared. Maybe you can find a theory about water that would explain this. It's the constant back and forth that is really at the heart of modern physics research.

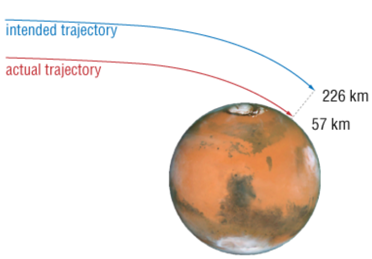
4. Measurement: Units

Rob

Here's Rob. He makes beer. These are some of the common (and uncommon) units used to describe volume. Every time you drink one his beers, you hope that he got his units correct!

liter	hectoliter	drop	cup	pint
barrel	gallon	quart	fluid ounce	tablespoon
teaspoon	cubic inch	acre-foot	stere	cord
tun	hogshead	gill	dram	cc
peck	hobbit	stack	omer	wey

Units are in a way a very cultural thing. In many cases, different cultures have adopted different units that they use to mark their measurements. Looking at the list above, if you're in the oil trading business, your unit of measure for volume would probably be the barrel. If you sell firewood to people, your unit of volume is the cord. Even though one of the goals of science is to transcend cultural differences, we have to still be very careful about units. Even amongst scientists, different groups have chosen different units to work in. This can be annoying at times, but, we know how to deal with it.

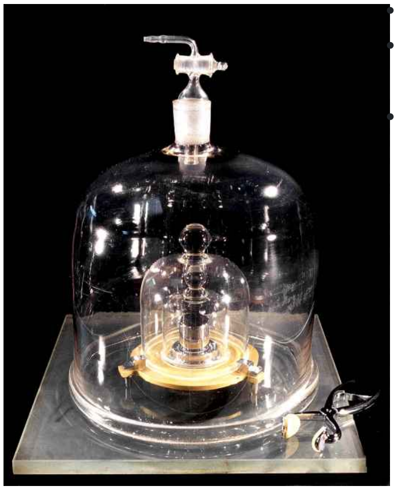


The most famous error involving units was the crash of a satellite intended for studying the climate on Mars. Standard and metric units got mixed up and hundreds of millions of dollars worth of scientific tools were burned up in the atmosphere.

The exact story is this: In 1998 the Mars Climate Orbiter was launched. Its mission was to fly to Mars, then enter orbit around the planet, and make measurements of the climate, atmosphere, and surface. The thrusters that directed the rocket were given instructions by several different software applications. One application produced the results of its calculations in the units of pound-seconds. Another calculation, which used the output of the first calculation as input, expected the input to be in Newton-seconds (the metric equivalent). These two units differ by a factor of about 4. So, upon approaching Mars, the spacecraft was about 4 times too close the surface. The atmosphere was much thicker closer to the surface, and the probe likely was destroyed due to stress associated with the heavier atmosphere.

Reference: [Nasa Report: http://mars.nasa.gov/msp98/news/mco990930.html](http://mars.nasa.gov/msp98/news/mco990930.html)

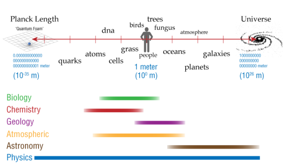
4.2 Fundamental Units



The Kilogram prototype

- Length Unit: meter, *m*, the distance traveled by light in a vacuum during a set time
- Mass Unit: the kilogram, *kg*, ~~based on a specific Pt-Ir cylinder kept at the International Bureau of Standards~~ Updated in 2019!
- Time Unit: seconds, *s*, based on the frequency of radiation from a cesium atom

Length Scales



Length Scales of Science

Length is an interesting concept. In physics, we often refer to the length scale of a particular phenomenon or effect. For example, the length scale that is important when talking about ocean currents is probably the kilometer, whereas the length scale that is dictates how atoms join together to create molecules is probably around 10^{-10} meters. People usually exist in the length scale of about a meter. Some say the overarching goal of physics is to find laws that apply to all the length scales. Others say this is not really possible, and that we need different physical laws for different situations.

4.3 Derived Units

Often, we'll combine 2 or more of the fundamental, or base, units to create a *derived* unit. This might be something like **miles per hour**, or **PSI** (pounds per square inch), or density:

$$\rho = \frac{kg}{m^3} = \frac{m}{V}$$

There are many examples of derived units. A lot of them are named after famous scientists. For example, the Newton, named after Isaac, is equal to a kilogram times a meter over seconds squared. Or, in a more readable format:

$$1\ \text{Newton} = \frac{1\ \text{kg} \times 1\ \text{m}}{1\ \text{s}^2}.$$

This is a good one to know.

4.4 Dimensions

Dimension has a specific meaning – it denotes the physical nature of a quantity. Some quantity is either a length, or a time, or a mass, or some combination of these.

Dimensions are denoted with square brackets, for example:

- Length [L]
- Mass [M]
- Time [T]

4.5 Dimensional Analysis

Take our familiar velocity: say miles per hour.

$$\textbf{distance} = \textbf{velocity} \times \textbf{time}$$

To analyze the dimensions of this, we would write:

$$[L] = \left[\frac{L}{T}\right] \times [T]$$

Notice how the dimensions of both sides match. [L]

4.6 Unit Conversion

We have to be able to convert between different units. For example, as you drive from the US in to Canada, the speed limit signs change from miles per hour (mph) into kilometers per hour (kph). In many of our physics problems, we'll use meters per second.

> Example Problem #1:
>
> Example:
>
> Convert 55 miles per hour into meters per second.

> Example Problem #2:
>
> Example:
>
> Convert 20 square meters into square feet

> Example Problem #3:
>
> Example:
>
> Convert 500 pounds per cubic yard into SI units

4.7 How do you know which units to use?

Use the context of the situation to guide you.

Also: who's your audience?

Case 1: The problem is given using a specific set: i.e. Imperial or SI. Then express your answer in whatever the problem variables are given in.

eg: I'm traveling at 20 feet per second - how far do I go in 60 seconds? Answer should be in *feet*.

Case 2: If the problem wording involves several unit systems. Then, unless otherwise indicated, express your answer in SI units.

eg. It takes Margeret 2 days to travel 60 kilometers. What is her average speed? Well, it could be expressed as 30 kilometers per day. That's a distance over a time. But It would be better to express it in meters per second - the standard SI units for speed. (about 0.35 m/s)

5. Notations

- Some quantities have one symbol used consistently
- e.g. for time, *t* is used

- Some quantities have many symbols used:
- e.g. lengths may be *x, y, z, r, d, h, etc*.

Just be consistent!

5.8 Scientific Notation and the metric prefixes

Metric prefixes in everyday use		
Text	**Symbol**	**Factor**
tera	T	1 000 000 000 000
giga	G	1 000 000 000
mega	M	1 000 000
kilo	k	1 000
hecto	h	100
(none)	(none)	1
deci	d	0.1
centi	c	0.01
milli	m	0.001
micro	µ	0.000 001
nano	n	0.000 000 001
pico	p	0.000 000 000 001

5.9 Significant Figures/Uncertainty/Measurements

This is NIST: Precision Measurements Lab.

Let them handle 10 decimal places.

Measurement is an entire discipline within modern physics research. If you need to know how much larger water gets when it freezes, you would consult a table of data about water. Labs such as NIST might measure how much water expands when it freezes, so when you design an all weather piece of equipment, you would be able to account for that change. Or, how much resistance a piece of pure copper might have. However, they will only report their measurements to a certain accuracy. That accuracy is determined by the quality of the measuring tools, as well as the experimental design they use to make the measurement.

In lab, you will perform measurements and be responsible for keeping an eye on your measurement accuracy.

5.10 Orders of Magnitude

Physicists love doing this: estimate to within 1 power of ten of some quantity from the world. For example:

- Distance to the Sun: 10^{11} m
- Length of a fly: 10^{-3}m
- Mass of a page from the textbook: 10^{-2} kg

> Example Problem #4:
>
> Estimate the circumference of the earth if it's 4000 km between NY and LA

6. Other things to know:

- Greek Alphabet
- Algebra
- Trigonometry
- Calculus
- Function Plotting