AP Physics/C

AP Physics/C is an intensive investigation of the principals that govern all the things around you. I am often heard to say that physics is the "study of the seemingly simple". In fact, physics is really very easy since it is just the quantification of your common sense experience. The problem is that it does require a level of comfort with mathematical expression many people never develop in their lives leave alone in high school. AP Physics/C in spite of the "calculus" basis is actually a bit easier to manage than the AP Physics/B class.

Physics/C doesn't cover as much material as the algebra based class. The first half of the course focuses only on mechanics so what the course doesn't cover in breadth it covers in depth. AP Physics/C is a close equivalent to the first semester course in physics at many universities. Some schools will give credit for a 4 or better on the AP exam at the end of the year. This is distinct from the B level course where credit is rarely given. If your intent is to major in the physical sciences or engineering then you would need to take a calculus based physics course in your first year. Even if the school you attend may not give you full credit they may allow you to be bumped into an accelerated or "honors" class. The advantage of this placement may be a significantly smaller class size (20-25 vs 200-300).

Because of the advanced nature of the material and the fact that this is, "officially", a second term physics class, it is necessary to make sure that everyone has a common background with some basic skills we use in our class. This summer packet, therefore, will contain material you may consider new or it may be review depending on your background. I will provide references to self paced online material to help your understanding if you need a little review. Since I will start class in the fall with an assumption that you have mastered most of the material in this packet it is important that you try your best to complete it before September.

I WILL COLLECT THE ANSWERS DURING THE FIRST WEEK OF CLASS!

KEEP THE BULK OF THIS PACKET AS A REFERENCE

<u>JUST TURN IN THE FINAL FEW PAGES</u>

A little note about calculators: AP Physics/C makes heavy use of vector math and lengthy calculations. The ti83+ and ti84+ are common tools in high school and every student usually already has one. They will serve very well. *If*, on the other hand, you are in the market for a new calculator – maybe your screen is cracked or faded or the paint you spilled on it is making the keys stick a little too often, may I recommend getting the ti89 as a replacement. The ti89 is a real powerhouse although it can seem a little daunting to use at first. Its real power comes from its ability to handle lengthy calculations while presenting the user with a full report of what you typed in. This capability is invaluable when dealing long calculations in order to make sure that the string of values you entered are, indeed, entered the way you believe they should be. The ti83+ and its kind do not give you this feedback and doesn't really allow for the review of previous entries. Combine this reporting ability with the fact that the ti89 handles units and vector math easily from the command line makes it is a powerful tool that will serve you well into your college career. The extra $20 spent on the ti89 will be well worth it. I have seen prices as low as $50 for ti89 on eBay for the generation 1 model which is more than adequate.

The point of this packet is that you should have a fairly good understanding of the following topics when we begin in September. I will assume everyone has been able to master the concepts listed below as we begin our class. For many of you these topics will be review. For a few, however, this material may be buried deeply in your subconscious. Don't fear, I will include many interactive references to self-guided instruction on these topics.

Contents

UNITS AND DIMENSIONAL ANALYSIS 3
- Metric System 3
- Seven Deadly Units 4
- Derived Units 4
- Operations performed on a value is also performed on its units 5

SCIENTIFIC NOTATION AND OTHER STUPID SCIENCE TRICKS 6
- Math with Scientific Notation 7
- Standard Prefixes 8
- Significant Figures 9
- Math with Significant Figures 10

VECTORS AND THEIR ARITHMETIC 12
- What are they? (should be a review) 12
- How we can describe a vector 13
- How to perform mathematical operations 13
- Breaking up is not hard to do 14
- Going Polar 14

BASIC KINEMATICS 15
- Study of simple motion without referring about what causes it 15
- What we can do with this information 16
- Simple manipulations 17

NOTION OF A FORCE 18
- The cause of all motion, indeed of all things physical 18

GRAPHING 20
- Data 20
- Labels 21
- Display 21

CONCLUSION 21

PROBLEM SETS 22

Units and Dimensional Analysis

Once upon a time there was a small, unmanned spacecraft whose job it was to take some measurements of a small red planet orbiting an unassuming little yellow sun in an almost forgotten section of the galaxy. The probe was sent by the ape-like descendants from the third planet in the hopes of learning new things about the fourth planet. The craft was designed to take measurements of the red planet's atmosphere. The ape-like descendants (who still thought digital watches were a neat idea) got their units confused. The designers of the craft were relaying information about the spacecraft to the controllers of the craft in an arcane "English" system of units. The controllers were using a more sophisticated set of units called "metric". Since neither the controllers or the builders were attaching units to their communications the drivers wound up pitching the 175 million dollar craft into the atmosphere of mars[1].

Physics is all about measurements. Measurements don't have any meaning if we don't have a common way to describe what we are measuring. If you are wallpapering a room and tell the paint store that your walls are "23" they will look at you with confusion. If you choose to add a dimension like "square barleycorns" then they might be slightly less confused but no more informed as they are unlikely to know what you used to measure the wall with.

Long ago we came up with the notion of a "standard" that is used to define not only the type of measurement we want to make but the actual dimension as well. Once you might have used your thumb as a unit of length. The problem is that your thumb might have been a different length than the guy who you wanted to buy some rope from. In comes the local ruler and he (it was almost always a "he") decided that it was the length of his thumb that everyone would use as a unit of length. This length would then be cast upon some wooden sticks and spread around. This is the origin of the "rule of thumb" we hear about today.

Metric System

In 1795, France officially adopted a decimal based metric system[2]. Strangely enough, we did also[3]. The overriding principal of this system is that the basic units should be based on standards accessible to everyone. Further, the dimensions should be divisible by 10 rather than halves, quarters and so on. The unit of length, the meter, was decided upon by taking the distance from the pole to the equator of the earth and dividing by 10,000,000. (*Hey, can you now figure out the radius of the earth in meters?*) Subsequent measurements in temperature and mass were similarly defined by using one of the most common substances on this planet: water. Today we base the unit of length on the universal constant of the speed light. The meter is defined as the distance a beam of light travels in 1/299 792 458 of a second. Indeed we have moved from an earth centric system to one based on fundamental constants of nature. It is now possible to communicate measurements to an extraterrestrial AP physics student because we can tell them the standards we base our measurements on.

---

[1] Mars Climate Orbiter http://www.seds.org/~spider/spider/Mars/ms98mco.html

[2] Chronology of the Metric System http://lamar.colostate.edu/~hillger/dates.htm

[3] By an act of congress in 1875, once the standards had been tightened.

As an aside, the fact that all the facets of physics are truly universal is one of the coolest things about learning this subject. The principals you learn are identical to that obtained by a student in San Francisco or China. Indeed the physical laws we learn about are true for you or another life form at the other end of the galaxy. A senior in what ever passes for a high school on the second moon of the fourth planet on Betelguese would cover the same topics as you will.

Seven Deadly Units

Now you may say to yourself, "how many different units do we need to measure all the things we might want to? There are thousands of possible things we *could* measure." Here is the neat part. We only need to define 7 units[4]. These units (called fundamental units) form the basis for any kind of measurement we might want to make on a physical system. If we need to measure something using units not in this set, we can combine these fundamental units into new combinations called "derived units." Some combinations of units are then given their own shorthand name usually honoring some engineer or physicist.

Type of Measurement	Fundamental Unit	Symbol
length [L]	Meter	m
time [T]	Second	s
mass [M]	Kilogram	kg
current [A]	Ampere	A
temperature [K]	Kelvin	K
count [Mle]	Mole	mol
luminosity [Lm]	Candela	cd
Candela, interestingly, may be dropped from this list soon which will bring the count to 6!		

That's pretty amazing! Imagine a restaurant that could serve anything you wanted but used only seven basic ingredients. Everything comes down to these basic, "fundamental", units. There are a ton of derived units that are combinations of these and even more conversion factors to relate units in other measurement systems but all physical quantities come down to these seven[5].

Derived Units

There are lots of things to measure so how do we break them down to these seven basic units? We can measure speed, acceleration, force, energy, power, voltage, charge, trouble; where do these units come from? They are usually obtained from formulas that relate these ideas to their basic counterparts[6]. In fact, remembering the units can go a long way to helping you remember the formulas. For example: Speed is a measure of how far you have gone in a given time. The derived unit for this must be something that looks like length per time. In SI units this turns out to be m/s. If you want to figure out how far you have gone in a given time then you need only multiply the speed times the time (in the same units) and you know how far you have gone. There is more on this point later.

The units for Acceleration can be figured out the way the units for speed was. Acceleration is the change in velocity per some unit of time. The units for velocity are m/s and a change in this per time would be m/s/s or $\mathbf{m/s^2}$.

---

[4] National Institute of Standards & Tech. http://physics.nist.gov/cuu/Units/units.html

[5] I should note that the choice of these units is somewhat arbitrary. They are made more for matter of convenience of measurement rather than "universality." Nevertheless these are defined as fundamental.

[6] ibid. A little further down the page. http://physics.nist.gov/cuu/Units/units.html

Type of Measurement	Unit Name	Combination of Fund. Units
Velocity		m/s
Force [F]	Newton	kg m/s^2
Energy, Work [E]	Joule	N m *or* kg m^2/s^2
Power [P]	Watt	J/s *or* kg m^2/s^3
Charge [C]	Coulomb	A s
Volt [V]	Volt	W/A *or* kg m^2/(A s^3)

All of the derived units come from their formula. Soon we will cover Force which, when unbalanced, results in an object of mass m accelerating: F=ma. Force is measured in kg·m/s^2 but because we get tired of saying "kilogram meter per second squared" we honor Isaac Newton and simply call this combination of units the Newton . There are a number of derived units (and the list keeps growing) but I have provided a short list that should serve as an example.

As you can see these units come from multiplying or dividing various combinations of fundamental units. In fact some startling discoveries have come about by physicists idly combining units to see what might come about. By tracking the units of measurement through all your calculations you can easily learn most of the basic formulas of physics[7],

Lets take a simple example: when a mass experiences an unbalanced force it moves. How does it move? First lets use our common sense. The bigger the force the faster something moves. This means that the force and the kind of movement is, at least, directly proportional. Further, the more massive something is the movement should decrease. This implies that the movement is inversely proportional. By examining the units we might predict the kind of motion we could expect. Based on our analysis the movement could have units of m/s^2 which is a velocity per unit time. This kind of motion we will later learn is called acceleration.

$$\frac{F}{m} = movement$$

$$\frac{[N]}{[M]} = \frac{[M][L]^2/[T]}{[M]} = [L]^2/[T]$$

Operations performed on a value is also performed on its units.

Keeping track of the units will help you follow through on the calculation. Lets take a more interesting example. (This can also be classified as a test survival skill.) Suppose you are asked some question about waves. A problem something like:

> An ocean wave traveling past a dock you are sitting on passes by (crest to crest) in 5 seconds . You determine the distance between the crests to be 5 m . What is the frequency and speed of this wave?

I forgot the formula! Now what!! Dimensional analysis to the rescue. Frequency has units of reciprocal time (1/time). The only time given in the problem is 5 seconds. Further, we are told that only one cycle of the wave moves by in this time. No matter what I do I had better have some combination that takes the inverse of this time. From the dimensional analysis alone I guess that the frequency must look something like the expression at the right, so the first problem is simply 0.2 Hz (Hertz being our shorthand way of saying " *reciprocal seconds*. "). The next barrier is to determine the speed. Again, we forgot the formula but from staring at speed limit signs every day I drive a car I know

$$f = 1cycle/5\,s$$

[7] There is a very cool chart illustrating how the different units can connect with one another. http://physics.nist.gov/cuu/Units/SIdiagram.html

that the units of speed are length per time (Miles per hour, kilometers per hour, etc.) The only length I have in this problem is the length of one cycle of the wave, 5m. and a time 5 seconds. If I divide the two I get a length per time. This can't be far from what I need.

Hey, I notice that the frequency is already 1/time. I'll bet that the speed is equal to the length x frequency. Lets try it!

$$v = ?$$

$$v = [L]/[T] = \lambda/t \xrightarrow{f=1/t} \lambda \cdot f$$

$$v = 5\,m \cdot 0.2\,Hz = 1\,m/s$$

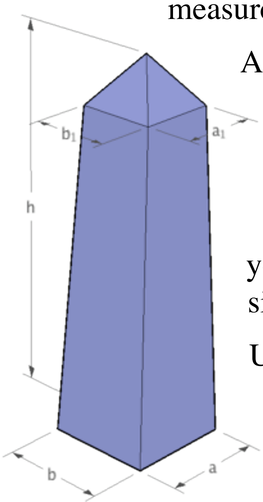
Not only does it look good (the units all work out) it is correct. Keeping an eye on the units and how they cancel can save your bacon in a pinch. Will it always work out this way? Not every time but much of the time it will get you in the right ball park. A calculation of the volume of a strange and arbitrary shape might be complicated and involved but no matter how complicated the formula, the end of the calculation had better yield something with units of length cubed (L^3.)

The formula for the volume of an obelisk given various length measurements a, a_1, b, b_1, and h is given as,

$$V = \frac{h}{6}\left[(2a + a_1)b + (2a_1 + a)b_1\right]$$

forget all the factors of 2 and 6 for a moment and we see that if we substitute L for all the measurements we get a result: Volume is L^3.

$$V = L\left[(L+L)L + (L+L)L\right] = L\left[L^2 + L^2\right] = L\left[L^2\right] = L^3$$



All of this has been by way of introduction. If you feel comfortable with the concepts of dimensional analysis (algebraic simplification with a purpose) then you can proceed to the first set of problems. If not, try reviewing the following web sites for some additional information and practice.

University of Guelph: http://www.physics.uoguelph.ca/tutorials/dimanaly/
There are plenty practice questions at this site.

Techniques for Physics http://physics.about.com/library/weekly/aa021503a.htm
This site provides more examples and applications.

University of Winnepeg http://theory.uwinnipeg.ca/physics/intro/node5.html
Quick on page review of the ideas embodied in dimensional analysis.

Try the first set of practice problems.

Scientific Notation and other Stupid Science Tricks

In order to run we must first learn to climb trees. err... something like that. In physics and engineering we will constantly be dealing with numbers that reach well outside the range of values we deal with on a daily basis. It can be awfully cumbersome every time you want to talk about a signal going down a wire that is **476000000000000 Hz** or a wavelength of laser light used in a fiber optic cable that is **0.00000063 m**.

I certainly would have trouble if I needed to compare a two values like **0.0000234** and **0.00000832** . Try it, imagine a table of these values and tell me you wont be reaching for a magnifying glass and a pencil trying to count all the zeros. There has to be a better way. There is…

Scientific Notation is a way of expressing large and small numbers in a way that makes them easy to compare. It certainly simplifies managing values when they are to be multiplied and divided. Sometimes scientific notation can be a little tricky when it comes to adding and subtracting but even here, with a little care, you can succeed without loosing track of zeros.

The basic idea is this. We want to express our number in terms of a number that lies between 1 and 10 and a product with a number that is a power of 10. Let me give an example:

Look at **476000000000000 Hz**, focus in on the first 3 digits. express this as " **4.76** " (a number between 1 and 10) and then count the number of jumps you have to make to move the decimal point from the end of the chain of zeros up to the place between the 4 and 7. This is the exponent you need for the power of 10. In this case it is **14** . The final number would be $\mathbf{4.76\ 10^{14}}$. The way you enter this into a calculator is by typing the mantissa (the 4.76) taping the EE key and then taping in the exponent (the 14). Try it and you have just entered the value for 476 Terra-Hz. There is more on standard prefixes later.

Expressing a very small number is also fairly simple. Take the other value indicated above: **0.00000063 m**. We, again, focus on the "significant digits" 6 and 3. Place the decimal point so that the number is between 1 and 10, in this case that is "**6.3**". Now, start counting the jumps from the place where the decimal point is now and where we want it between the 6 and 3. I count **7**. Because we counted to the right we put a minus sign in front of the 7 so we get $\mathbf{6.3\ 10^{-7}}$ for 630 nanometers. To complete the description the way you enter this number into the calculator simply tap the mantissa (the 6.3), tap the EE key, and then tap in the exponent (the -7). Do note that most calculators distinguish between a minus (for subtraction) and a negative (for designating negative numbers).

GET OUT OF THE BAD HABIT TAUGHT BY SOME MATH COURSES of using the "`*1Ø^`" notation! If you don't place your parentheses correctly or forget to use them the calculator will report an incorrect result. Learn to use the IEEE notation of "`6.3E-7`", *This is one of my biggest pet beefs with the ti83+ calculator; the EE key is a 2nd function.*

Math with Scientific Notation

Doing math with scientific notation becomes easy once you know the trick to adding and subtracting exponents. $\mathbf{1/10^{-7}}$ becomes $\mathbf{10^{7}}$! See we simply reversed the sign of the exponent. $\mathbf{1/10^{7}}$ becomes $\mathbf{10^{-7}}$ for the same reason. We reversed the sign of the 7. Multiplying two large or small values becomes simply a matter of adding or subtracting exponents. Thus the product $\mathbf{10^{3}}$ x $\mathbf{10^{-8}}$ is just $\mathbf{10^{-5}}$, becomes a simple addition of the exponents. Dividing two values is just a matter of doing the same as invert and multiply. The quotient $\mathbf{10^{3}/10^{-8}}$ is just $\mathbf{10^{3}}$ x $\mathbf{10^{8}}$ or $\mathbf{10^{11}}$. You can get some more information on this from an astronomy site[8] which does a nice job of summarizing this information.

Another very good reason for switching to scientific notation is that it makes the job of determining the number of significant figures very easy. More on this later.

---

[8] http://plabpc.csustan.edu/astro/math/notation.htm - Arithmetic

Standard Prefixes

It is awkward to keep having to say " *I had ten to the minus 6 thus and such* " every time you are trying to say something simple. Lets face it, scientists and engineers are lazy people unlike AP Physics students. We don't like to work hard. So, we invent short hand ways of expressing really huge or ridiculously small numbers. This short hand turns out to be very useful when you want to compare values without getting hung up on the exponents. Here is a table of standard engineering prefixes that you are likely to see in this course and around funky locations like hangouts frequented by engineering types[9].

Symbol	Prefix	Multiplier	Example
a	Atto-	10^{-18}	10^{-18} boys = 1 attoboy or 1 aboy
f	femto-	10^{-15}	10^{-15} bismol = 1 femto-bismol or 1 f-bismol
p	**pico-**	10^{-12}	10^{-12} boos = 1 picoboo or 1 pboo
n	**nano-**	10^{-9}	10^{-9} goats = 1 nanogoat or 1 ngoat
μ	**micro-**	10^{-6}	10^{-6} phones = 1 microphone or 1 μphone
m	**milli-**	10^{-3}	10^{-3} pede = 1 milipede† or 1 mpede
c	**centi-**	10^{-2}	10^{-2} mental = 1 centimental† or 1 cmental
d	deci-	10^{-1}	10^{-1} mate = 1 decimate or 1 dmate
Da	deca-	10^{1}	10^{1} cards = 1 decacards or 1 dacards (of course!)
K	**Kilo-**	10^{3}	2 10^{3} mockingbirds = 2 kilomockingbird or 2 kmockingbird
M	**mega-**	10^{6}	10^{6} phones = 1 megaphone or 1 Mphone
G	**giga-**	10^{9}	10^{9} lo = 1 gigalo or 1Glo
T	Tera-	10^{12}	10^{12} bulls = 1 terabull or 1 Tbull
P	Peta-	10^{15}	10^{15} l = 1 petal or 1Pl
E	Exa-	10^{18}	10^{18} terrestrials = 1 exaterrestrial = 1 Eterrestrials
† Remember that it is easy to distinguish a millimeter from a centimeter… The millimeter has many more legs.			

The highlighted areas identify the more common prefixes we are likely to see in this course. Note that when the exponent is <0 the prefix is lower case and visa versa.

Check out this "Powers of Ten[10]" web site for a cool demonstration of the scaling by powers of 10 in spatial directions. Take careful note of what lies between the electron shroud of an atom and its nucleus.

---

[9] For a complete list visit: http://physics.nist.gov/cuu/Units/prefixes.html

[10] Powers of Ten http://www.wordwizz.com/pwrsof10.htm

Significant Figures

By this stage we know how to express numbers with units and to use scientific notation to write values of extremely large and small values. Now we take up the final topic in how to describe numbers taken from measurements.

Up until now you have been fed numbers like the food on your table. You have no idea where they come from they just appear with arbitrary precision. In physics we visit the farm and learn where our numbers come from: Measurement.

In chemistry, significant figures was the bane of your existence… or was it? It is actually a code system for conveying precision. You can't really appreciate what significant digits are all about unless you see that the context and purpose of all numbers is to measure something. Numbers come about because we want to keep track of a measurable quantity. Take goats for instance. Way back when shortly after we stopped chasing small furry things in our BVDs and we figured out how to pen them up, the natural thing to do was to count them. This way when we got together with our friends at the mall (another new invention) we could brag effectively about how many more I had than you. Just before the discussion became really heated, there would arise a question of exactly how you came by that number. By simply saying 5, for example, we would be telling our listener that we were certain of that value only to the extent of ±0.5 goat. Since goats don't usually come in 1/2 sizes (or so my goat farming cousin tells me) this detail was quickly overlooked. But what happens when you are measuring parcels of land? How do I explain how heavy that electron (the blue one) is that is sitting in my garage? Significant figures are tightly connected to the measurement you are making.

Take a look at the picture on the right. I could express the measurements of these tablets seized by customs service in one of two ways:

We have 2 tablets that measure 9mm in diameter. We used a ruler that had 1mm increments as its finest gradation. The precision of this measurement is, therefore, only good to an estimated plus or minus 0.5 mm.

or

We have 2 tablets of 9. mm diameter.

Which statement is shorter? Imagine having to give a list of 100 measurements? Wouldn't it get tedious to have to describe the precision of the instrument all the time? The Significant Figures convention is just such a way to get around this problem in a concise easy way. The second statement, in a simple one step format, tells us that the precision of the measurement is ±0.5mm. The mere existence of the decimal place gives us this clue.

Significant Figures is a set of rules for the writer as well as the reader. We use these conventions to communicate information about the precision of any measurement we have made. If I write: 25.00mm, I am telling you I used a device that is precise to ±0.005 mm. It may be that my eyes are bad and I really can't see to better than ±2cm, but this isn't your concern (that is a question of accuracy). I am claiming the precision indicated.

"Enough already, what are the rules!" The rules are simple and fairly obvious except for when numbers get particularly large. You may have heard about seven rules, five rules and other combinations. I have reduced the rules for keeping track of significant figures down to two:

1. **The number of significant figures is equal to the number of digits present <u>EXCEPT</u>**
    a. **zeros to the left of the number and**
    b. **zeros to the right used to pad the number to its place.**
2. **Zeros to the right of a decimal place <u>are</u> significant.**

Consider the following examples and explanations:

Number	Sci. Not.	Sig. Fig.	Precision	Why?
123 g	$1.23\ 10^{2}$ g	3	±0.5 g	Easy, just count the digits. Rule 1.
0123 m	$1.23\ 10^{2}$ m	3	±0.5 m	Ignore zeros to the left. Rule 1a.
12.34 kg	$1.234\ 10^{1}$ kg	4	±0.005 kg	Count the digits again. Rule 1, again.
12.30 kg	$1.230\ 10^{1}$ kg	4	±0.005 kg	First of the tricky ones. This zero isn't just a place holder. It is a deliberate signal by the reporter that the value was measured to this precision. Rule 2.
12300 J	$1.23\ 10^{4}$ J	3	±50 J	Second of the tricky ones. The zeros that appear after the 3 are just there so we convey the correct order of magnitude. Rule 1b.
12300. J	$1.2300\ 10^{4}$ J	5	±0.5 J	Notice what the decimal point did! It marked the zeros as significant. It signaled that all the values, right down to the last zero were part of the measurement. Rule 2.
0.0034 N	$3.4\ 10^{-3}$ N	2	±0.00005 N	The zeros in front of the 34 were just there to hold its place again. Rule 1b.
In some textbooks you will see a little overbar to designate a significant 0. Generally speaking, you only see this in textbooks. Once you shift to expressing numbers in Scientific Notation there is no need for this convention.				

Pay particular attention to the column expressed in scientific notation. The exception rules disappear! Just count the numbers in the mantissa (the number in front of the ten$^{\text{to some power}}$). This is one of the reasons we bother with this way of writing values. I deliberately included units to drive home the point that significant digits are part and parcel of relating measurements. Through measurement and analysis is how we can say we "understand" our world. You can get a more complete idea of this concept from some sites on the web[11]. When you are ready you can test yourself using an evaluatior[12].

Math with Significant Figures

What if we have to calculate numbers based on these experimentally imprecise values? "Isn't the result dependant on the precision of the values we measure?" you say. The answer is "Yes, it certainly is and there are rules governing how we combine values so we maintain this precision reporting accuracy throughout the calculation.

---

[11] Significant Figures http://www.towson.edu/~ladon/sigfigs.html

[12] Significant Figure Self Tester http://lectureonline.cl.msu.edu/~mmp/applist/sigfig/sig.htm

Before we begin remember that we apply the necessary rounding at the end of the calculation. If we truncate along the way then our calculation would be subject to another kind of systemic error called rounding error. It is “ok” to keep the 20 or so decimal places in your calculator as long as those numbers don’t get written down on paper.

The rules for adding and subtracting numbers with limited precision are fairly straightforward and are best described by going through the following exercise:

Suppose I have two values: 2.3m and 1.20m and I wish to add them. By implication (from the previous section) we know that the 2.3 m value is actually 2.3±0.05m and the 1.20m value is really 1.20±0.005m. Lets add the extreme, worst case limit, of the values. At one end, we get 1.205m+2.35m = 3.555m and at the other we get 1.195m+2.25m = 3.445m. Split the difference and we see that the middle value is 3.5±0.055m or by rounding the error value 3.5±0.06m. I think you can see where the first rule is going to come from:

When adding or subtracting values the answer should reflect the precision of the least precise value you are adding or subtracting. The errors add[13].

Values and Operation	Answer	Explanation
2.3m + 1.20m =	3.5m	Per the example above. The least precise value is the 2.3m
5.26s - 1.2s =	4.1m	The least precise value is the 1.2s. The result of the operation is 4.06 which rounds to 4.1.
2.4kg - 2.3kg =	0.1±0.1kg	The error on this value is ±0.1 which means the result of this calculation can be legitimately 0 kg.

We can play the same game with multiplication and, by extension, division. We get a slightly different rule. If I multiply two values I need to add their %error[14] to get an estimate of the final error. Consider the following example: 2.3m and 1.20m are the results for a measurement of a table top. What is the surface area? 2.3±0.05m * 1.20±0.005m = 2.7±0.07m^2. The way I got here was to, again, multiply the extreme limits of the initial values and determine the error from the spread of the 2 calculations.

[13] Ok, if you have had a proper course in statistics the errors don’t really “add,” they convolute. What this means is that you really add the root mean square of the errors. Suffice it to say, adding the errors is good enough for our purpose.

[14] The %error of a value is found by dividing the error by its value and multiplying by 100%. 2.3 ±0.05m has a %error of 0.05/2.3*100% = 2.2%.

When multiplying or dividing values the final value should reflect the same number of significant figures as the value with the fewest significant figures.

Values and Operation	Answer	Explanation
2.3m * 1.20m =	2.7±0.07m^2 or 2.7m^2	2.3 has 2 significant figures so the answer should have only 2 significant figures.
5.26N / 2.1m/s^2 =	0.40±0.01kg or 0.40kg	The least precise value is the 2.1m/s^2. The result of the operation should only reflect the same number of significant figures. Note that if we simply report 0.40kg we are implying that the value is precise to ±0.005kg but this small fib is allowed.
9.0N 6.2m =	58±0.4J or 58J	Here is a situation where we lied the other way. We actually know the value to greater precision than we report but because of the rounding rules we over estimate the final error.

Now I should point out at this point that these rules are approximate. As we develop our skills with some higher forms of mathematics, (namely: derivatives,) we will dispense with these approximate rules in favor of a more powerful set of regulations known as ERROR PROPAGATION. But that is for another time.

Vectors and their Arithmetic

We are familiar with number lines and how to add and subtract values cast on these number lines. They are a convenient tool for illustrating how values can combine to give results of numerical operations. These types of values are called ***scalars***. What you may not have realized is that this representation (called a graph, by the way) are not the only kinds of numbers one can represent. Many quantities have properties that go beyond simple magnitude or value. These quantities require describing them with more than one value. The quantities are called "***vectors***." Vectors are multidimensional numbers. While vectors can have any number of components, we will get started with the simplest form of vector that has only 2 components: the two dimensional (or 2D) vector. Know, however, that the treatment we will give here can be extended into 3, 4 and even higher dimensions.

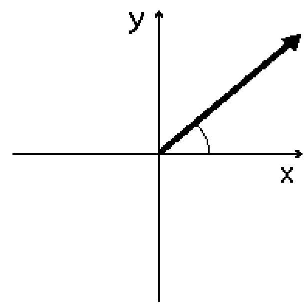
What are they? (should be a review)

The simplest example of a physical quantity that needs to be described by a vector is **displacement**. Displacement is a measure of your location away from some starting point. For example, suppose you start at your home and are sent out to fetch some bread from the store. Your home is the origin and when you arrive at the store you decide to phone a friend and let them know where you are. They have never been to the store but they know where your house is. You might describe your location as being "5 miles from home" but is this sufficient. Simply relaying your distance would put you on a circle with a 5 mile radius from your house. To locate yourself you would need to specify a direction as well. This is what vectors are all about. You would say I am 5 miles from my house on a heading of North by North East (NNE). (Well, unless you spent a lot of time on old sailing ships you probably wouldn't do this, but you get the idea.)

With the 2D vector we need to specify two values: a distance and a heading (a length and an angle) or two distances (a length along one coordinate and a length along another). There is always an assumption when you specify a vector: there is a defined coordinate system in which you spell out its components.

How we can describe a vector.

For a 2D vector we need at least two values to describe it. 3D vectors require 3 values and so on. In order to describe a vector we need a coordinate system. Conventionally we use a right handed coordinate system where the angle is given in degrees measured counterclockwise from the x-axis. The vector in the figure at the right can be described with a length (like 5m) and an angle (such as 40°). The start of the vector is called the "***tail***" while the pointy end is called the "***head***".

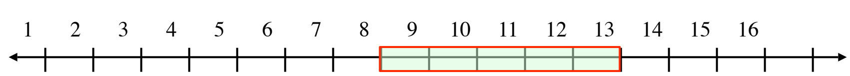


The diagram at is called a "scaled" vector diagram. The reason for this description is that the length of the vector is, obviously measured in centimeters or some other convenient length measure. What is represents, however, may be a vector that may be measured in meters, meters per second, Newtons, Volts per meter or some other suitable vector quantity. This is where most students encountering vectors are most confused. The best way to get a better understanding of a vector quantity is by using an interactive web site where you can see the relationship between vectors and the physical quantities they represent. Just keep in mind that these diagrams are just the two dimensional analog of the number lines you used in grade school. Using these diagrams one can tackle the seemingly mysterious world of vector math. One of the best places to get a better grasp of how to describe and represent vectors is to visit the web site: HyperPhysics[15].

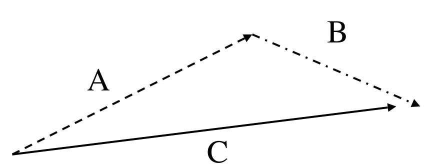
How to perform mathematical operations.

When you learned about number lines you discovered a way of representing mathematical operations like addition on that line. For example, when you add 5 to a number it doesn't matter where you place the "5" length as long as it is located at the end of the value you are summing it to. Thus the example above illustrates the result of adding 5 to 8; the result is 13.

Adding vectors is done in much the same way. We simply translate the vectors so that the tail of one vector lines up with the head of the other. The result, like the simple number line illustrated above is just a new vector drawn from the tail of the first vector to the head of the other. The best



way to practice this method of adding vectors is to draw "scaled" values on a sheet of graph paper and measure the resultant (the vector that represents the result of the addition). With the advent of computer graphics we can do this on a computer and get some of the same feel for how this is done. Please visit the Vector Math site[16] to get some practice at adding scaled vector values.



---

[15] Vectors http://hyperphysics.phy-astr.gsu.edu/hbase/vect.html

[16] Vector Math http://www.surendranath.org/Applets/Math/VectorAddition/VectorAdditionApplet.html

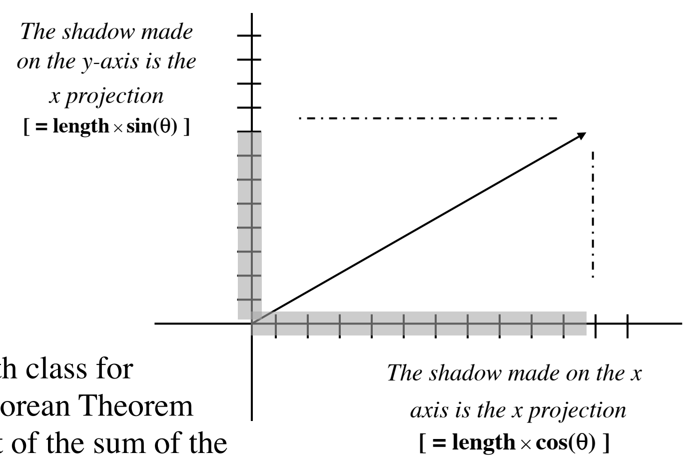
Breaking up is not hard to do

Adding vectors using scaled diagrams is one way to perform arithmetic on vectors but with scaling, measuring, and rescaling there is often a loss of precision that can be undesirable. There is a more precise way to add vectors and that is the "**component method**" that can be sketched below.

A vector is a directional value that can be represented in a different coordinate systems. When someone says "I am pushing the car with a force of 500N in a North-East direction" they have implicitly given you a vector described in a "polar" coordinate system. This is the most common way to describe a vector. It seems natural to express a directional value in terms of its magnitude (the 500N in the example) and a direction (North-East). There is another way to represent the vector and that is its expression in a rectilinear coordinate system we are all familiar with called a "Cartesian" coordinate system (named after René Descarte, the famous 18th century mathematician). In this system we convert the length and angle into an expression in terms of the vector's projection in the x and y coordinate. Think of trying to shine a light on the vector from above and looking at the shadow along the x axis. This would be the "x" projection along the x-axis. Similarly, we can think of the projection in the y-axis as the shadow the vector would make if we shone a light from the side.

The mathematical way of performing this operation is to measure the length of the vector and multiply it by one of two functions. It is easy to derive the function to use as you are already familiar with the acronym SOH-CAH-TOA. Consider the vector to be the hypotenuse of a right triangle. In this circumstance the height of the triangle is simply the hypotenuse (length of the vector times the sine of the angle it makes with the x axis. The length along the x axis is, correspondingly, the length of the vector times the cosine of this same angle. You should be able to derive this relationship from the "Sine is the opposite over the hypotenuse" acronym described above.

You can get some additional practice by going back to the Taiwan University site and taking note of the components of the vectors you draw on the screen, Add the x components and y components in separate columns. You will notice that they equal the components of the resultant. All that remains is to convert the vector back to polar coordinates.



Going Polar

To return a vector, described with x and y components, back to polar notation you simply apply formulas you learned in your math class for triangles. To get the length you use the Pythagorean Theorem ($c^2 = a^2 + b^2$) by simply taking the square root of the sum of the squares of the two components. The angle is simply the arcTan of the ratio of the y and x components. Try to see if you can convert any of the vectors you have drawn on the web site back and forth from the polar representation (magnitude and direction) to the component representation (x and y values).

Taking the difference between two vectors is simply adding one vector to the negative of the other. A vector multiplied by –1 is simply the same vector pointing the other way. Just redraw the vector from the head back toward its tail and do either of the same operations as above. You can go back to the web site and draw the second vector over the first but in the opposite direction. Note how the components relate to the values from the first vector. The short cut to this same process is to take the tails of the two vectors and put them together and draw the resultant from the head of the second vector to the head of the first. You can see how this is done using the web site at Taiwan University.

Basic Kinematics

Kinematics is the investigation of the mathematical basis of motion without paying any attention to how it takes place. In short it is the study of motion. Some of these formulas you already know. You have used them routinely when ever someone asks "How long will it take you to drive to the store?" In order to answer this question you would simply estimate distance you need to travel and divide by you approximate speed. In order to figure out how many miles you traveled while moving at 55mph for the last 1/2 hour you would multiply the speed by the time to arrive at approximately 27 miles.

Study of simple motion without referring about what causes it.

Kinematic equations are vector equations which means that we can use them to operate on vector quantities. We begin by describing the notion of position. "Remember, No matter where you go, there you are.[17]" We have to have some point of reference. Lets call one possible reference point, your room in your home. As you go out you can define you location as a vector that contains information about how far away you are from your room and in which direction. As you continue to move around this vector will change. The distance from your room may get shorter or longer or the angle you make with respect to north may vary but your position is changing. This location vector is called **displacement**. Given this definition of you position, if you were to run around a race track your net displacement would be zero; you wind up where you started, As you move around you, nevertheless, cover ground. You do run a 1/4 mile as you go around the track. This measurement of your travel is called the "**distance**". It is very important to keep these two concepts separate as we move forward. You may want to go to the physics classroom site[18] to gain some further clarification on this point. Be sure to work through all the pages.

Once we are clear on the notion of displacement and distance we can define their rate of change. This is useful for all the reasons listed above. Once we know things like the rate of change of position we can begin to make predictions on how where things will wind up if they are allowed to run free for a while. The rate of change of displacement of an object is called the "velocity" of that object. It is defined as being simply change in displacement divided by the change in time or in a more

$$\text{Average Velocity} = \frac{\Delta\,\text{position}}{\text{time}} = \frac{\text{displacement}}{\text{time}}$$

---

[17] Buckaroo Bonzai Through the Eighth Dimension. MGM Studios.

[18] HyperPhysics (U of Georgia) http://hyperphysics.phy-astr.gsu.edu/Hbase/mot.html

formal mathematical sense: $\vec{v} = {}^{\Delta\vec{x}}\!/_{\Delta t}$, where $\Delta\vec{x}$ is just the measure of the change in the displacement and Δt is just the time it takes to accomplish this change (the Δ means change).

$$\text{Average Speed} = \frac{\text{Distance Traveled}}{\text{Time of Travel}}$$

The average speed is similarly defined as the change in distance covered by the change in time. More formally: $s = {}^{\Delta d}\!/_{\Delta t}$. Notice that because distance is not a vector quantity (it is a scalar) we don't have the little arrows over the symbols. You should refer to the physicsclassroom[19] site for some more help with the definition and the distinction between the two ideas.

Once we understand the meaning of velocity we can go one more step. We can define a new quantity called **acceleration**. **Acceleration** is the rate of change of velocity. Mathematically we can describe this as $\vec{a} = {}^{\Delta\vec{v}}\!/_{\Delta t}$. In a way acceleration is like velocity. Velocity is a change in displacement per time while acceleration is a change in velocity per time. They are also both vector functions. The consequences of this will be clear in a moment. Acceleration is the quantity that describes how fast you are speeding up or slowing down as in the phrase "That car can go from 0 to 60 [mph] in 8.3 seconds!" The statement reflects a change in speed (60mph – 0mph) per 8.3 seconds.

We can go on like this but we need only continue this description of changes to this level. It turns out, in physics, we don't need any special definitions to any higher order of change than this.

What we can do with this information.

With these definitions in place we can work out a bunch of formulas that help to describe where we are at any time once we know how fast you are moving and the magnitude of your acceleration. Consider the definition of velocity: $\vec{v} = {}^{\Delta\vec{x}}\!/_{\Delta t}$ we can manipulate the quantities here to figure out how far we have gone in a given time:

$$v = {}^{\Delta x}\!/_{\Delta t} \;\Rightarrow\; v \cdot \Delta t = \Delta x \;\Rightarrow\; v \cdot \Delta t = x_f - x_i \;\Rightarrow\; x_i + v \cdot \Delta t = x_f$$

The final position is just the initial position plus any displacement due to movement.

[19] ibid. http://hyperphysics.phy-astr.gsu.edu/Hbase/mot.html

What happens if there is a change in the velocity during this time? The derivation is slightly more involved but the final formula is just as straightforward:

$$a = \Delta v / \Delta t \Rightarrow a \cdot \Delta t = \Delta v \Rightarrow a \cdot \Delta t = v_f - v_i \Rightarrow v_i + a \cdot \Delta t = v_f$$

$$v_{avg} = \frac{v_f + v_i}{2} \Rightarrow v_{avg} = \frac{(2 \cdot v_i + a \cdot \Delta t)}{2} = v_i + \tfrac{1}{2} a \cdot \Delta t$$

$$x_f = x_i + v_{avg} \cdot \Delta t \Rightarrow x_f = x_i + \left(v_i + \tfrac{1}{2} a \cdot \Delta t\right) \cdot \Delta t \Rightarrow$$

$$x_f = x_i + v_i \cdot \Delta t + \tfrac{1}{2} a \cdot \Delta t^2$$

The final position is just the initial position plus any displacement from a starting velocity and one half the displacement from the acceleration. You should use unit analysis to verify that the final formula in the above collection is, at least, dimensionally correct.

Simple manipulations.

Armed with three equations (listed below) we can now solve any motion problem provided we have enough information about the object in motion. For example lets start with a simple problem:

> Suppose you are waiting at a traffic light and as it turns green your best friend drives by (at the speed limit of $15\, m/s$) if the maximum acceleration your car can obtain is $1.5\, m/s^2$ how long will it be until you catch up?

$x_f = x_i + a \cdot \Delta t$	$v_f = v_i + a \cdot \Delta t$
$x_f = x_i + v_i \cdot \Delta t + \frac{1}{2} a \cdot \Delta t^2$	$v_{avg} = \frac{v_f + v_i}{2}$

Your initial speed was $0.0\, m/s$ (you were at rest) and your friend was passed you at $15\, m/s$ You will cover the same distance using the following formulas:

$$x_{friend} = x_i + v_i \cdot \Delta t = x_i + 15\, m/s \cdot \Delta t \qquad \Downarrow \qquad x_{you} = x_i + \frac{1}{2} a \cdot \Delta t^2 = x_i + 1.5\, m/s^2 \cdot \Delta t^2$$

$$x_{friend} = x_{you}$$

$$15\, m/s \cdot \Delta t \qquad = \qquad \frac{1}{2} 1.5\, m/s^2 \cdot \Delta t^2$$

Notice how it doesn't matter where you define the starting point, x_i, because you only count the distance from the stop line. Solving the above expression for Δt we find that we will catch out friend in 20 seconds. The only problem is that we will be going $30\, m/s$, or twice the speed limit:

$$v_f = v_i + a \cdot \Delta t \;\Rightarrow\; 0\, m/s + 1.5\, m/s^2 \cdot 20 s = 30\, m/s$$

(notice how the units of seconds divide away to give use units of speed?)

So the last calculation was a little rough? That is where some practice comes in. Learning to consider the question being asked carefully and matching the right expression to the words is a fair amount of what this class will be about.

Notion of a Force

In the 16th century there was an idea that all motion was caused by something called impetus. Impetus was infused into an object when it was hurled in some direction. This caused the object to move, fly or transport itself until it ran out. A projectile launched from a cannon or a catapult would fly as long as its store of impetus was maintained. When it gradually ran out it would fall back to earth. Aristotle set this idea in motion and it certainly seemed to satisfy most people's experience. Machines and carts handled from the time of the Greeks to the early Renaissance all had a fair amount of friction. These machines would only go if you kept pushing them.

A few years before the birth of a man named Isaac Newton lived an Italian scientist named Galileo Gallilei. Bored with sitting in church he decided to note that a swinging incense burner or lantern (we are not sure which) would move with the same period regardless of when it was last pushed. He made the connection of this repetitive motion with the motion of a rolling ball and decided to study it further. He came to the remarkable (and somewhat heretical) conclusion that the final speed of a ball rolling down a hill did not depend on how steep the slope was; it merely depended on how high the hill was.

Galileo made a nearly fatal mistake. After making his discovery he chose to publish his results. He wrote not in the Latin that only church trained scholars could read but in the vernacular Italian which anyone could access. The church couldn't suppress the document. It was translated into numerous other tongues and eventually reached England where Isaac Newton was starting to ask many of the same questions about the world around him that Galileo had. Newton probably read Galileo's "*Diologia*" [20] because it had been translated into and out of many different languages and had spread around Europe.

Newton considered that there must be a connection with the simple act of a falling object and the motion of the moon which also was a kind of falling object. From this he arrived at a revolutionary idea. Galileo got to his conclusion through careful experiment. Newton came to his revelation through painstaking mathematical analysis. He satisfied himself and others by linking his ideas to other peoples measurements. In Newton's characterization of motion there was no need for a stored "substance" called impetus. Everything comes from the initial push, after that the object just maintains its state of motion. Newton characterized his ideas by laying out three seemingly simple laws. Though simple to state, the laws have deep consequences.

The cause of all motion, indeed of all things physical[21].

The first law was the idea that things will just continue along unless they are affected by a "force." A "force" is just something that pushes or pulls on an object. What Newton was saying is that if all the forces on an object are in balance so that their net effect is zero then that object

[20] Ironically he probably read it in Latin which was one of the many languages it had been translated into from the vernacular italian.

[21] Hyperphysics site (again) http://hyperphysics.phy-astr.gsu.edu/Hbase/Newt.html

will stay still or continue in along a straight line at constant speed. This was a revolutionary idea. The idea that an object moving at constant speed in a straight line (same velocity) was the same thing as standing perfectly still was a concise encapsulation of all that Galileo had concluded. He postulated that uniform motion (motion with an unchanging velocity) was nothing special. Uniform motion was a natural effect of any object. Only if you desired to change the state of motion did you need to do something: apply a force.

The second law was a quantification of how a force caused an object to change its state of motion. This is the formula that is used in most of the problems assigned in beginning physics but it, like the first law, has much deeper implications.

$$\vec{F} = m \cdot \vec{a}$$

This is a deceptively simple formula. What it says in words is that when a force is applied to an object it experiences an acceleration. If you remember from the kinematics section, acceleration is a strictly defined concept. Acceleration is defined as a change in the velocity. This is the first subtle interpretation of the formula. The formula states that the force doesn't change the position or any higher order change than the velocity change. The only facet of motion that is affected is the first order change in velocity. We could just as easily write the formula as:

$$\vec{F} = m\frac{\Delta\vec{v}}{\Delta t}$$

Note that the equation doesn't care what the initial velocity is or what the position of the particle is. A net force only drives a change in the velocity. The F in the equation has a little arrow over it indicating that this is a vector equation. Some of the consequences of a vector equation are beyond what this packet is trying to introduce but suffice it to say that the change will occur in the same direction as the net force, There is nothing in the equation that changes the direction between the force and the acceleration.

The third most basic law of Newton is sometimes known as the "action-reaction" law. For every applied force there is an equal and opposite reaction force. I look at it this way: Superman can't fly[22]. If I push on you the force I apply to you is equal and opposite to the force you apply to me. If I tug on a rope attached to the wall then the wall tugs back with the same force. This seemingly obvious relationship has interesting implications. Consider your current position, sitting on a chair or on the sand at the beach[23]. As you sit there is a force trying to pull you into the center of the earth. The exact nature of this gravitational force is still under some investigation but its characteristics we understand extremely well. The earth's mass pulls on you and you pull on the earth. (It is so much bigger that when you jump up you will experience the

---

[22] In the original rendition of Superman comics back when it first appeared, Superman didn't "fly", he "jumped". This has interesting ramifications when one considers the needed acceleration to "leap a tall building in a single bound." Superman didn't rush up to objects, suddenly stop (what was he pushing against?) and then start up again in another direction (again, what was he pushing against? What was pushing against him?)

[23] If you are currently at the beach reading a summer packet then you are definitely AP Physics material! Now, go jump in the ocean and pick this up later when you get home.

greater acceleration.) The effect of this is that as you sit the chair you are on exactly balances this force. Since you are effectively stationary the force of gravity must be balanced by another force exerted by the chair. This reactive force is called the "normal" force.

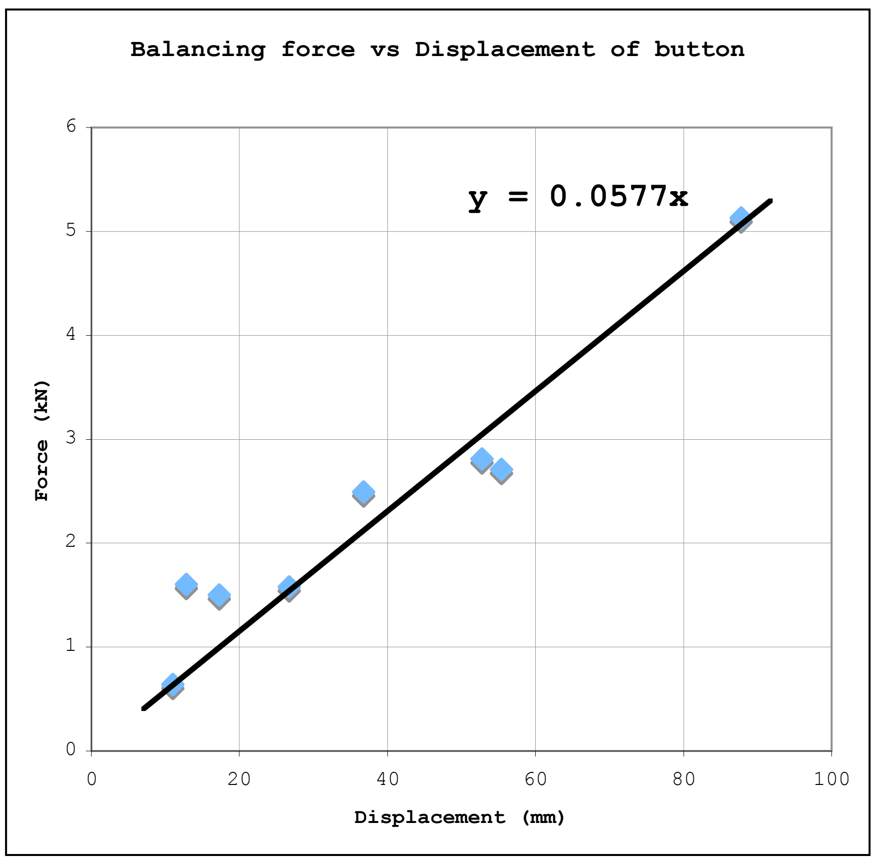
Graphing

I am putting this section here because it doesn't fit neatly anywhere else but it is fundamental to the whole process of physics. Many of the rules presented here you already know but they are sufficiently important that they bear repeating in case you are unclear about anything.

Pos (m)	Force (N)	⇒	Pos (mm)	Force (kN)
0.0128	1,599		12.8	1.60
0.0110	641		11.0	0.64
0.0173	1,504		17.3	1.50
0.0267	1,581		26.7	1.58
0.0528	2,806	⇒	52.8	2.81
0.0368	2,494		36.8	2.49
0.0554	2,710		55.4	2.71
0.0878	5,129		87.8	5.13

Physics is about measurement. Measurement of sets of related values lead to models of behavior that allow us to make predictions, Predictions are how we get through each day (that's why you read your horoscope each morning ☺). We use graphs to make such associations. When we measure the effect of some measurable action on some object we are trying to understand the cause and effect relationship between the two. Graphing this relationship is an important pictorial way to represent this information. From this picture we can develop a mathematical model from which we can make predictions.

You all know how to make a graph so I will focus on the critical elements you need to consider when making a graph for use in physics. All the rules we have learned so far about error values, dimensions, and scientific notation will apply so keep these ideas in mind as we go through the process of making charts for reports.



Data

Start with some data. Presumably the data are from experiments where the independent (numbers you control) values are correlated with the dependent values (numbers the experiment gives). We chart these pairs of numbers on a 2D grid by first deciding on a scale. As AP students I presume you have more than a passing familiarity with this process so I will focus on the details. Choose a scale where you can express the values in a range from 0.1 to 100.0. This means you start by looking at your numbers and choose a single order of magnitude (scientific notation) which can express the values in this way. The table of raw values becomes modified using our prefixes. This will make for a much neater graph.

Labels

Label your axes with the dimensions of your measurement. The axes are what you measured. The title of your graph (overall) can be more creative but it should reflect what relationship you are trying to demonstrate. I might label this graph: "*Balancing force vs displacement of button*."

Display your fit. Most data you take should be cast in a way that requires a linear fit. If you are determining the fit from the graph manually (rather than using a least square or med-med fit) make sure you take your slope from the line and not from the data directly!

Display

Note the size of the graph on the previous page. Notice how it occupies at least 1/5 of the page. You graph is central to your experiments. Make the data points visible and make the chart count. I will hand out a guide on how to use Excel to make well formatted graphs for lab reports in the first few days of class.

Conclusion

Hopefully you didn't find this material too daunting. I began this packet with the idea that for most of you this should be review. For the handful that are new to physics, do not despair, the mathematics is something you should have seen before so if you can just muscle your way through the equations that will be preparation enough. Try to make extensive use of the web sites as they are designed to be self-guided. If you really get stuck you can email me at pBeeken@byramhills.org. You may also know someone else who has had physics who can give you a helpful start. In any case just the effort alone should set you on the right path.

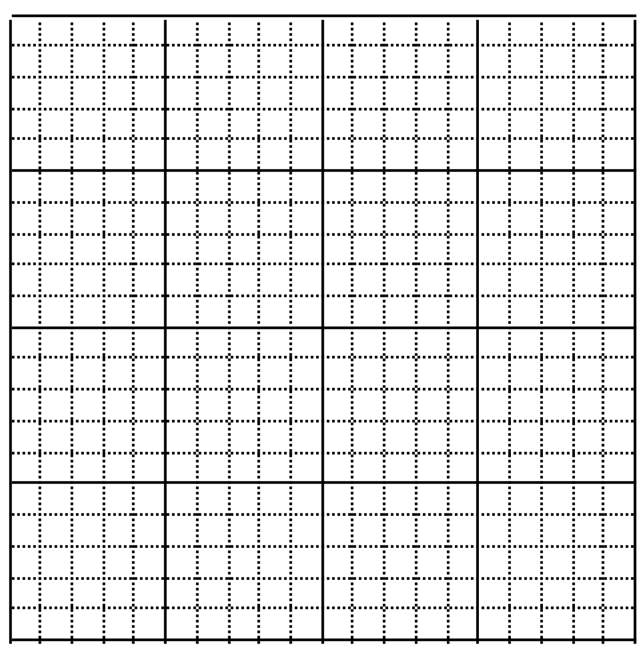
We will begin in September assuming you already understand basic kinematics and will move from there. I will operate with the assumption that you have already mastered basic vector manipulation so we will deal with the more sophisticated methods when we use these tools in our class.

Problem Sets

1. How many significant figures are in the following values:
   a. 273.16 ______
   b. 3,000,000 ______
   c. 5280 ______
   d. 186,000 ______
   e. -240,000 ______
   f. 0.070830 ______
   g. 707 ______
   h. 0.00623 ______
   i. -6.52×10^{-2} ______
   j. 1000 ______
   k. 40.070 ______
   l. 9.040×10^{5} ______
2. Rewrite the following values using standard prefixes:
   a. 8.3×10^{5} m ______
   b. 2.75×10^{4} A ______
   c. 1.42×10^{-2} s ______
   d. 6.54×10^{-7} m______
   e. 6.03×10^{15} N ______
   f. 4.99×10^{-14} J______
3. Complete the following operations considering the correct propagation of significant digits (don't forget the units either):
   a. 10.7 m + 6.01 m + 152.110 m ______________________
   b. 4053 J – 60 J ______________________
   c. 52 N × 7.913 m ______________________
   d. 98.4 m / 10.375 s ______________________
   e. 6.31×10^{3} m × 7.9136 m × 1.242 m____________________
4. Plot the following tables on a graph and use the results to answer the posed questions:
   a. What is the average velocity of the toy car whose data is presented here?[24]

Time (s)	Position (m)
2.10	2.40
3.23	3.72
3.92	5.28
5.01	6.00
6.05	7.28

   b. What distance did this car cover from its start when the clock read 10 seconds?



[24] Please, please, please DO NOT CONNECT DOTS! Get your information from the line of best fit. Not from any single pair of points! USE A RULER!!!!

Use the following table of velocity data for the following questions.

Time (s)	Velocity (m/s)
14.0	12.84
16.1	14.18
18.0	13.56
19.8	15.77
22.0	15.59

c. What is the average acceleration for the object in this study?

d. What is distance did this object cover for the specified time range (14.0 to 22.0 seconds)?

e. Assuming the acceleration has been uniform, what was the total distance covered from the beginning (0 sec)?

5. In the movie King Kong, the giant ape, tragically falls from the empire state building. How long did it take him to fall the 380m? What was his speed when he hit the ground? (a=9.8 m/s^2 downward)

6. A kangaroo can jump to a vertical height of 2.7m. How long before he hits the ground? (a=9.8 m/s^2 downward)

7. A sports car accelerates from rest to 95 km/hr in 6.2 s. What is the average acceleration in m/s^2?

8. In one scene of a movie, two locomotives (shades of Perils of Pauline?) approach each other on a track. If each is making 95 m/s over the ground with an initial separation of 8.5 km, how long before they meet?

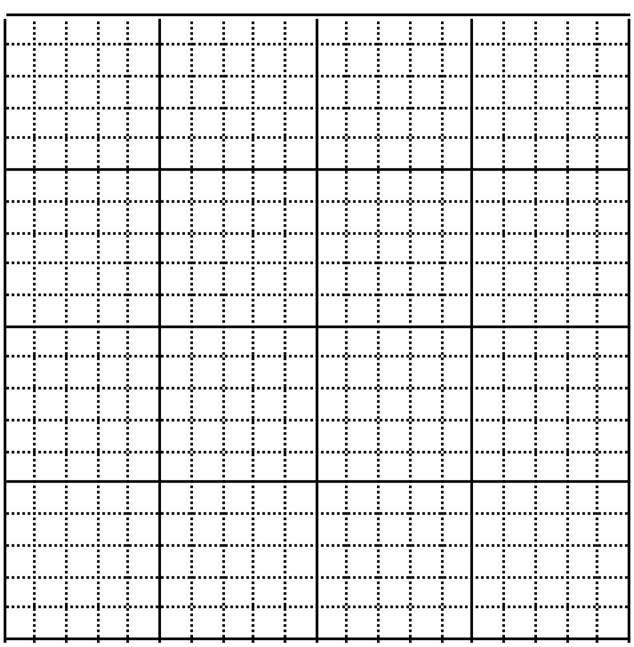
9. A person jogs around a standard quarter mile track eight times (2 miles) in 17.5 min. What is the runners average speed? What is the runners average velocity?

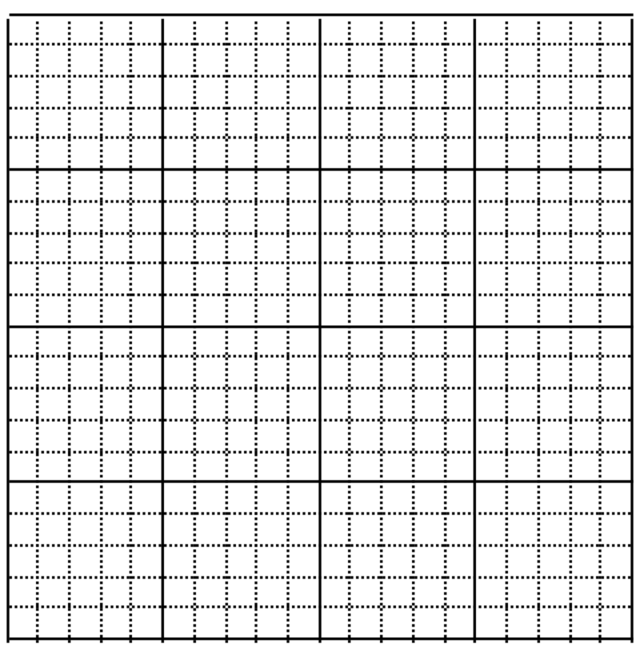
10. At highway speeds a particular automobile accelerates at about 1.6 m/s^2. At this rate how long does it take to get from 80 km/hr to 110km/hr?

11. A car slows from 25.0 m/s to rest in 5.00 s. How far did it travel in that time?

12. What is the stopping distance for an automobile with an initial speed of 90 km/hr and a human reaction time of 0.3 s (the time it takes to hit the brake) and (a) an acceleration of $-4.0\ m/s^2$ and (b) an acceleration of $-8.0\ m/s^2$?

13. Graph the position vs time and velocity vs time of an object for 4 seconds after it falls from a plane that is traveling at 120m/s:





Look at your graphs! Do the signs and the magnitudes represent realistic values for the time of the fall?

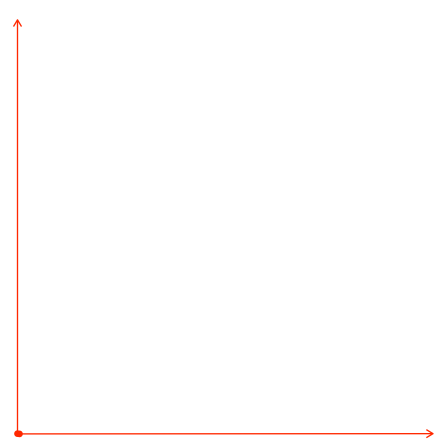
14. What is the displacement of an object that first moves 30 m NorthWest and then travels 20 m East?

15. What is the resulting force on an object that is being pulled with 600N to the left and 350N to the right?

16. What would the resulting force be if the object in the above question were being pulled in the same direction?

17. What would the resulting force be if the object in question 15 were being pulled at right angles?

18. Use the graphical method (you can use the website if you know how to print from the screen) to add the velocity vectors 25 m/s at 30° above the horizontal axis and 30 m/s at 120° above the horizontal axis. (*and yes, you will need to find a ruler*)



19. Try to accomplish the same task in 18 using the component method.

20. Perform the following operations for the vectors[25]:
    $\vec{A} = 1.3\text{m}\angle 23°$ $\vec{B} = 3.2\text{m}\angle 76°$ $\vec{C} = 2.1\text{m}\angle 143°$ $\vec{D} = 4.3\text{m}\angle 245°$

    a. $\vec{A} + \vec{B} =$

    b. $\vec{B} + \vec{D} + \vec{C} =$

    c. $\vec{D} - \vec{B} =$

    d. $\vec{A} + \vec{B} - \vec{C} =$

21. A net force of 30N is applied to a box sitting on a sledge on a nearly frictionless frozen pond. The sledge and box have a combined mass of 50 kg. If the sledge is initially at rest, what is the acceleration of the sledge? How much distance will the box cover in 10 seconds?

22. A 90,000 kg schooner sits at the dock un-tethered. If you push on the bow (the front) of the vessel with 30N of force, how much distance can you make it move in an hour?

23. Gravity exerts a uniform force on every object close to the surface of the earth. This force is proportional to the mass of the object. The net effect of this is that all objects experience the same acceleration of 9.8 m/s^2. If an object has a mass of 50 kg, what is the magnitude of the gravitational force? (We refer to this force as the "Weight of the object")

24. If I drop a 5 N weight from a height of 10m what will be its speed just before it hits the ground? If the object weighted 15 N, what would its speed be?

25. Consider the table of units attached to this packet. a) If I multiplied a force (measured in N) times a distance (measured in m), what would be the special name given to the resulting combination of units? b) If I then took this result and divided it by a unit of time (measured in s), what would the resulting special unit be?

---

[25] *This is a chance to practice using your calculator in new ways (ti83+ and ti84+ has ScienceTools, the ti89 can perform vector math right on the command line!*