Physics 30A, Mr. B. Panas - Course Outline

Introduction

Physics 30A is not an easy course. I am not trying to scare anybody away; I am just trying to be honest. I also honestly believe that this course is a lot of fun, and has a lot of really neat stuff in it. If you are willing to work hard, you will find it very rewarding. Welcome!

Topics

We will be working very closely with your textbook "Physics" by Giancoli (3rd edition). With very few exceptions, we will be doing everything in chapters 1 to 7, some of chapter 8, a small part of chapter 11 (which will be combined with chapter 5) and the chapter on fluids. If you are able to, please read ahead in your textbook!

Homework

I know you have heard this before, and probably won't believe me (yet) but you must do your homework to succeed in this course - even if you have been "coasting" so far in other courses and doing well. The biggest mistake that students make when they take this course is that they do not take me seriously when I say this. Even on the rare occasion where I don't assign homework, you should take some time to review, and/or work ahead (or catch up!) If you do your homework faithfully, you may find that there are some problems you are unable to do. This is good. What would be the point of doing them, if you already knew how? When you get "stuck" I advise the following: First try the problem in a different way, draw a diagram if applicable. If that doesn't work try getting help from a friend. If that doesn't work try looking in the solutions manual (I'll talk about this in class). If none of these help you, then (and only then, please) come to me for help. **I am always happy to help, but only after you have attempted to help yourself**. By the way, getting "unstuck" on problems is called *learning*.

Marks Breakdown

Marks will come from 5 places:

1 **Tests**: At the completion of each chapter is a chapter test, with the exceptions of chapters 1 and 2 which will be tested together, as will chapters 5 and a portion of 11. This means that there will be eight tests of approximately equal value. **If you are absent for a test you will receive a zero for that test.** You will be able to write the test late only if you talk to me, and convince me that you missed for a legitimate reason. The only legitimate reasons for missing a test are illness, and school sponsored events. Doctor / Dentist appointments etc. are not

legitimate reasons, unless you speak to me in advance, and can convince me otherwise - in which case you should try to arrange to write at a different time. Please note that some tests have bonus questions - you may not get credit for bonus questions unless you write at the scheduled time.

2 **Quizzes**: Occasionally we will do a short quiz, which will test you on recent topics covered (as recent as the last class!) This is my way of forcing you to keep up with the material. These quizzes are marked on a "right or wrong" basis with no possibility of part marks (which may always be earned in tests). If you are absent at the time of the quiz, then you will receive an "omit" which means that you neither gain nor lose anything.

3 **Computer Quizzes**: On the computers at the back of my room, is a program which contains multiple choice quizzes on the topics we are studying. I will be assigning these quizzes frequently, which are to be done **outside of class time**, by a certain date (usually the day of a test). The computer is available for you to do these quizzes at almost any time that I am in the room, including when I am teaching other classes.

4 **Labs**: Unfortunately, in the AP physics, we don't have a lot of time for labs. I am hoping to have us do at least 3 labs throughout the course. There will be a handout on lab reports at a later time.

5 **Exam**: The exam is 3 hours, and will consist of multiple choice and long answer problems. It will be based on all of the material we cover. I have heard rumors that it is not very easy.

How to Succeed in this Course

Physics, more so than most subjects, builds heavily on the material you learn. In other words, in order to learn chapter 4 well, you need to really understand chapters 1 to 3, and to learn chapter 8 you will need a good understanding of all seven previous chapters. Too often, students write a chapter test and then hit the reset button in their brains, thinking that they get to start fresh in the next chapter. This will not work here.

Realize also that to succeed you must learn physics which is really a way of thinking. There is no way to bluff this - it is simply not enough for you to memorize some facts, and how to do a problem or two.

Keep an open mind. Physics is largely common sense, but there will probably be times when you simply will refuse to believe something I say. Chances are very good that I will be right, but I would rather convince you of this, and have you agree with me, than force you to just say what I say on a test. This is best done if you ask questions when you need to. Good Luck!

Physics 30A Class #0

This class: Chapter 1
Note that Chapters 1 and 2 will be combined for testing

Welcome to physics 30A. I give handouts similar to this, instead of having you copy down notes. We can then spend our time talking, and doing examples instead of writing. By the way this is class number "zero" because it really only introduces physics - physics itself begins next class.

Chapter 1 really has no physics in it. It introduces physics as a science, gives a little history, and reviews some math. Let's start by addressing the question of what physics is.

Physics can be described as "the part of science that is not Biology or Chemistry". This may not seem very helpful, but if you think about it, it actually tells you a lot, since you probably have a really good idea of what science is and what biology and chemistry are all about. A good historic account of the sciences (including physics) can be found on the separate handout I've given you.

Physics is hard to nail down a good definition for, but the best I've seen is something like "the study of matter and energy, and how they interact with each other." A more informal description of physics is "trying to figure out how the universe works - in particular, all of the rules that seem to always apply to any "physical" situation".

Just as science is broken down into three major branches (physics, chemistry & biology), each science is further divided into areas of study. Physics is commonly broken down into <u>mechanics</u> (study of motion), <u>electricity and magnetism</u>, <u>optics</u> (study of light), and <u>thermodynamics</u> (study of heat / temperature effects), <u>fluids</u> (study of gases and liquids), <u>modern physics</u> (physics that is less than a hundred years old (no kidding) or newer), and a few others that I won't get into here.

At this point, you should be well acquainted with the metric system and the SI set of units. You should be able to work with scientific notation, convert units, and work efficiently with trigonometry and algebra. You should also know how to use your calculator. Just to be safe we will review these topics in class.

For Homework:
- Leisurely skim over chapter 1, carefully read section 1-5
- Memorize Table 1-1 (Metric Prefixes) on page 9
- Memorize Table 1-2 (Base units) on page 10
- Do Ch 1 Problems 1-3, 8-13, 15, 21, 22

Physics 30A - Class #1

This Class: 2-1 to 2-6

We are beginning our study of physics with mechanics - the study of motion. Mechanics itself can be subdivided into two areas: kinematics - the study of how things move (speed, acceleration, etc.) and dynamics - the study of why things move (force, energy etc.). But first ...

Vectors and Scalars

This is a very important topic, although at its heart, this is math and not physics - we will use this math so often however, that you may come to think of it as physics.

Numbers can generally be lumped into two categories: scalars are "ordinary numbers" - that you have been using all of your life (well maybe not much in the first couple of years). Examples of scalars are 10, -5, π, $\sqrt{2}$, etc. We say that scalars have only one part to them: magnitude which is essentially a size. Vectors have two parts: they have a magnitude, but they also have a second part: direction. An example of a vector would be "5 to the east" - notice how it has a magnitude part (5) and a direction part (east). Think of "5 to the east" as a single number (a vector number) and not as a number partnered with a direction.

Quantifying Motion

Physics is all about quantifying (describing numerically) various aspects of the universe. We will begin by describing how we quantify motion:

time is the duration of the motion (or a part of the motion). The second (s) is the SI unit for time, and time is represented by the symbol "Δt" in equations. (although "t" is often used instead ... for our purposes, t and Δt can be used interchangeably).

position is a measure of location (often of an object) with respect to some chosen coordinate system. The coordinates of a point on a graph may be considered to be a measurement of that point's position. The metre (m) is the SI unit of position. Note that position is intimately related to distance (below). Position has more than one symbol representing it in equations, though "x" and "y" are common - we will rarely need to symbolize position.

distance is the amount of space separating two positions. It is commonly used to measure how "far" an object has moved, in which case the two positions referred to above are the position of an object at two different times. The metre is the SI unit of distance, and distance is represented by the symbol "d". Note that while we will use a "d", many textbooks (including your own) use the symbol "Δx " instead, where the triangle is the Greek letter "delta" which stands for "change in" ($\Delta x = x_f - x_i$). Δx can then be read to be the "change in position" - a little thought will show that this is the same as the description of distance above, provided the object moved in a straight line. If an object does not move in a straight line, then distance measures the length of the path travelled.

displacement is the vector cousin of distance. While distance is "how far", displacement is "how far ... and in which direction". A difference between distance and displacement is that for an object in motion, distance is the length of the path travelled while displacement is how far (and in which direction) the object ended up from the start position - regardless of the path travelled. The metre is again the SI unit, and the symbol for displacement is a boldface d (when typed) as in "**d**". When handwritten, a vector arrow is drawn above the d, as in "$\vec{d}$"

speed is a measure of how fast an object is moving, or more specifically, the rate at which it's distance is changing. The SI unit for speed is m/s, and speed is represented by the symbol "v" in equations. The defining equation for (average) speed is $\bar{v} = d / t$. Note that a bar (¯) above a symbol denotes average. If the speed is constant, then the reference to "average" is not needed, and so $v = d/t$ for constant speeds.

velocity is the vector cousin of speed. It has the SI units of m/s, is represented in equations by **v**, and has a defining equation $\bar{\mathbf{v}} = \mathbf{d} / t$. Again, if the velocity is constant, then this becomes $\mathbf{v} = \mathbf{d} / t$

Section 2-2 will actually be more important in the future, but it is basically saying that speed is not "absolute" - but rather is relative to some chosen coordinate system. Unless otherwise stated, we will use the earth as our frame of reference.

Section 2-3 is about changing units, which we have seen already

Equation Summary

$\bar{v} = d / t$	This equation has two versions: one with vectors (v = velocity, d = displacement) and one with scalars (v = speed, d = distance). It applies to any type of motion, as only average speeds or velocities are involved.
$v = d / t$	Again, two versions (as above). This equation however, only applies to objects moving with constant speed (or velocity).

Homework: Read 2-1 to 2-6, Questions 1-6, Problems 1-11

Physics 30A - Class #2

This Class: 2-7

Acceleration is a very important concept in physics. Whereas velocity tells us how fast something is moving (and in which direction), acceleration tells us how quickly the velocity is changing. Unfortunately, velocity and acceleration are often confused - perhaps this is because words like "fast" are sometimes used to describe both.

Consider this question: Car A can go from 0 to 60 km/h in 5 seconds, while car B can go from 0 to 60 km/h in 6 seconds. Which car is faster?

My answer to this question would have to be "there is not enough information to tell". To me, the word "fast" is a description of velocity (at least primarily). From the information given, both cars are capable of reaching the same velocity - 60 km/h. If more time is allowed, perhaps one of the cars (A or B) is capable of going up to 200 km/h while the other car is capable of 220 km/h - then we would know which car is faster.

If you initially thought that car A was faster - then you were probably not thinking of velocity, but acceleration. Both cars changed their velocity in the same way: a change from 0 to 60 km/h - but since car A did it in less time, you may want to say it is faster - but I would prefer to say that it *accelerates* greater (or faster).

A proper definition of acceleration would be "the rate of change of velocity". This is important wording - you will see similar wordings in the future, so know that the "rate of change" of something is basically saying "how quickly something changes". The equation for rates of change are always the same: we need to know how much something changed by: Δsomething, and how long the change took to occur: time. The equation that defines acceleration is: $a = \frac{\Delta v}{\Delta t}$. Notice that acceleration a will have units which are velocity units (m/s) divided by time units (s). The units will therefore be "meters per second, per second" or (m/s)/s which is better written as m/s^2. Note that acceleration is a vector, and so should have a direction - although we sometimes are only concerned in the "magnitude of the acceleration" which does not contain direction.

Now is a good time to talk about a shortcut for direction. For motion that is one dimensional - in a straight line - we can choose one direction to be the "positive" direction, and the other one "negative". Which is positive is completely our choice, though it is standard to let positive be North, East, or up, if the motion is along one of those directions. This means that if something moves at 5 m/s [East], we can declare that "East is positive" and that **v** = +5 m/s.

Homework: Read 2-7, Questions 7-13, Problems 12-15

Physics 30A - Class #3

This Class: 2-8 & 2-9

No handed out notes for this class - we will instead use this page to derive the kinematics equations.

Homework: Read 2-8 & 2-9, Problems 16 - 28

Physics 30A - Class #4

This Class: 2-10

In the last class we derived the five kinematics equations. It is worth repeating that these five equations are only valid for cases when an object moves with an acceleration that is constant - in other words, an object must change very "smoothly" from one velocity to another. This section deals with a specific situation in which this occurs: objects being pulled downward by gravity.

It is obvious that falling objects accelerate - that is, they change their velocity as they fall. The exact nature of this acceleration is quite complicated: the mass of the object, its shape, and how it is dropped all play a role the acceleration, as does the air pressure, temperature and composition. The truth is that physics of this type is exceptionally complicated (even beyond an AP course) and so we do something that we will often do in such a case: we simplify the situation by ignoring some of the details. We must acknowledge that by doing so we are sacrificing some accuracy, but if we limit ourselves to certain situations, our approximations will be quite good.

The simplification that we will make here is that there is no air. The fact is that "air resistance" can be safely ignored for objects that are reasonably massive compared to their size, and are not moving too quickly. We will <u>always assume that air resistance is not involved</u> in any situation we come across, unless we are specifically instructed to do otherwise - or if we wish to analyze a situation in a "real life" setting.

Remarkably, in the absence of air resistance, the acceleration of a falling body is constant. In fact, the acceleration of a falling body does not depend on any of the factors that were originally listed above! It comes down to an incredibly simple situation in which <u>the acceleration of all falling bodies is the same</u>. This "acceleration due to gravity" is so important that it is given its very own symbol, for use in equations: g. The value of g is about 9.8 m/s^2 near earth's surface, but this is not a universal constant. You can think of g as being two things at the same time: ① it is the value of the acceleration of an object that falls, and ② it is the "strength of gravity" at some location. The value of g does change a little from one spot on earth to another, as the strength of gravity depends on where exactly you are (more on this in chapter 5). It can be very different if on a different planet, or place such as the moon (where g is about 1.6 m/s^2). As of now you have *memorized* that g near earth's surface is 9.8 m/s^2.

The idea that all falling objects accelerate at the same rate does not agree well with our everyday experiences: we know that a falling tissue and a falling computer do not fall at the same rate. Common sense tells us that heavy objects fall faster. Common sense is often wrong.

It is very easy to show that heavy objects do not automatically fall faster. This false belief comes from the way air resistance *usually* affects objects. Consider two pieces of paper: one a full sheet and the other only half a sheet (the full sheet will be twice as heavy). Crumple up the half sheet to a small ball, and leave the full sheet flat. If they are both dropped, it will be very easy to see that the full sheet (the heavy one) falls slower. It can be shown that if both are dropped in a vacuum (where there genuinely is no air) both will surprisingly fall together, at the same rate as falling marshmallows, cats and anvils (although I strongly discourage dropping cats in a vacuum). In class I will try to convince you that all objects fall, accelerating at the same rate in 2 more ways.

The above is applicable to problems as <u>we now automatically know the acceleration</u> of any object that is being pulled on only by gravity: g (by the way, we assume we are on earth where $g = 9.8\ m/s^2$ unless told otherwise). Problems here will often need us to realize the vector nature of the kinematics involved. To deal with the directions, for each problem we must state which direction we choose to be positive. The convention we will use is simple: if an object moves up at any point, we will choose up to be positive (this means that $a = -g = -9.8\ m/s^2$). If on the other hand, the object only moves in a downward direction, we will choose down to be positive (and so $a = g = 9.8\ m/s^2$). Actually state this in your solution to a problem! (ex: "Up is +")

Another thing you must understand is that the acceleration of an object being pulled on only by gravity is 9.8 m/s^2 (positive or negative depending on what is chosen to be positive) in the downward direction <u>for the entire time that it is moving</u>. Convince yourself of this by realizing that while moving up, objects decelerate (which is an acceleration opposite the direction of motion: down), and while moving down they pick up speed (which an acceleration in the direction of travel: again down). At the critical instant in time in which it is neither moving up nor down (at the very top of its motion) it must still be accelerating at 9.8 m/s^2 in the downward direction! If it was not accelerating (as many would believe) then its velocity should be constant (that is what 0 acceleration implies) ... constant velocity of zero should mean the object stays up there in the air levitating!

Homework: Read 2-10, Questions 13-16, Problems 30-46 (omit 35)

Physics 30A - Class #4.5

This Class: 2-11

The notes here are going to be exceedingly brief, as most of the development will come from class.

We have been studying motion, and have identified some kinematics type information that is worth keeping track of, namely velocity, displacement, acceleration and time. For an object in motion, we can keep track of how these quantities change with time, by graphing them.

A graph itself can be analyzed in many ways. For us, two especially important concepts will be that of <u>slope</u> and <u>area</u> contained under the graph.

Slope is a measure of "how steep" a graph is, and you should be familiar with how to find the slope of a straight line as "rise over run". Notice that by "rise" what is officially meant is Δy and "run" means Δx. Thus slope can be generically written as slope = $\Delta y / \Delta x$.

For our graphs, we will not use the generic "x" and "y". In their places will appear the kinematics quantities. In particular, we may be interested in "position time graphs" (which may be abbreviated as x-t, or d-t, if displacement is substituted for position). Notice that the slope = $\Delta d / \Delta t$, which can realized to mean velocity!

Similarly, on a v-t graph, the slope is $\Delta v / \Delta t$, which can be identified as acceleration!

Your knowledge of slopes is probably limited to finding the slope of a line. This may be extended to find the slope of a curve, at least at some particular spot on the curve by the use of a tangent line - this will be covered in class.

Although familiar with both area and graphs, you may have not seen the "area of a graph" - which is really nothing out of the ordinary except for one thing: area is considered positive if above the x-axis, and negative if below the x-axis. Also, the units of the area contained within a graph follow naturally by multiplying the units of x and y axes.

With further analysis, it can be shown that a d-t graph has a meaningless area, while a v-t graph has an area which means displacement, and an a-t graph has an area which means Δv.

Homework: Read 2-10, Questions 17, 18, Problems 47-54

Physics 30A - Class #5

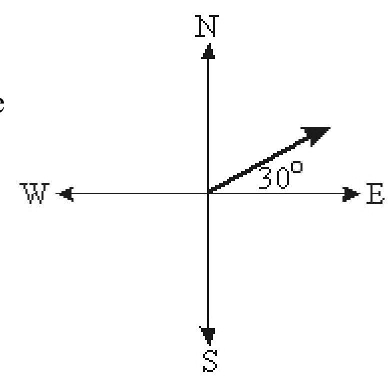
This Class: 3-1 to 3-3

As we have already seen, a vector is a number that has two parts: magnitude (size) and direction. A common way of representing vectors, is with a drawn arrow, since arrows have two parts: length (a "magnitude") and direction. Arrows then, become a very important visual aid in working with vectors.

Our focus today is on vector addition. But first, some language. When you add two numbers together, you call the answer the "sum". For vectors, we may call the answer to addition the sum, but we instead often refer to it as the resultant (**R**). The word "resultant" then simply means the answer you get when adding vectors.

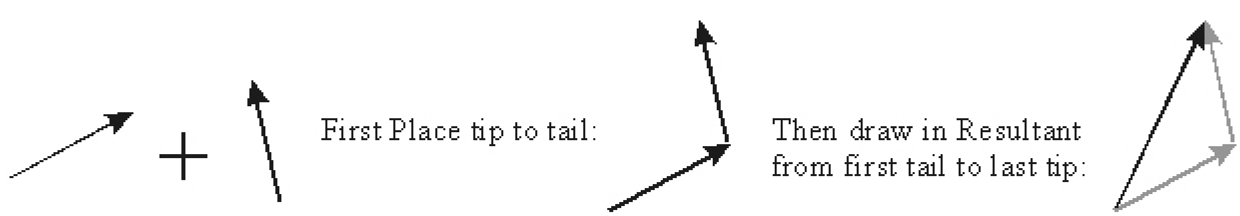
A drawn arrow has two ends to it. We will refer to these two ends as the tip (with the arrow head) and the tail (the other end). The direction that the vector points in, is typically described in terms of the compass points: north, south, east and west. Vectors that don't point in one of these four directions have their direction indicated by an angle (in degrees) and a description of where that angle is found in this format:

{Magnitude of Vector} @ {Angle in degrees} {Compass direction 1} of {Compass direction 2}



For example: If the vector shown here has a magnitude of 5, then it should properly be described as a vector that is "5 @ 30° north of east". A common problem students have is in deciding which compass direction to list first. The solution is to notice that all angles will be measured between the vector and a compass direction (in this case, the vector and East). The compass direction that is part of the angle is always listed last, as it is the reference direction. 30° north of east essentially says "go east, then go 30° to the north". In the example shown, we could have also described the vector as being "5 @ 60° east of north".

One method for adding vectors is called the graphical technique. In the graphical technique, you draw the vectors carefully with a ruler, to scale, and place them "tip to tail". The resultant can then be found by drawing in a new arrow that starts at the tail of the first vector, and extends straight out to the tip of the last arrow, as shown here.



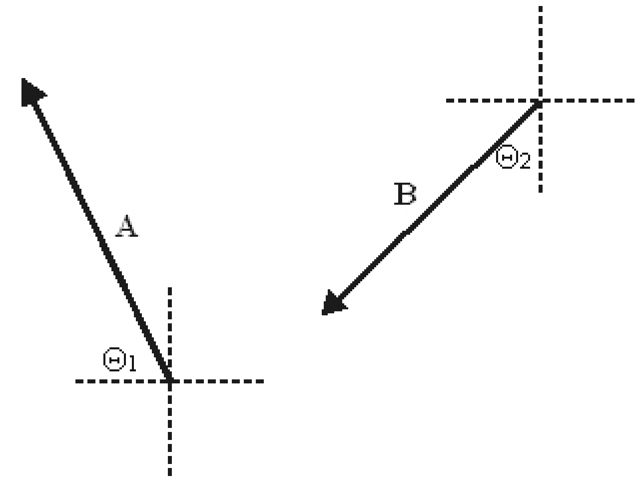
The newly drawn resultant could then be measured with a ruler, and its direction determined with a protractor. This technique is limited by the precision of these measurements. A better way to add vectors, which we will always use (even if a problem says to do it graphically!) is called the Analytic approach.

I like to break up the analytic approach into three levels: level 1 is when the vectors are parallel or antiparallel to each other. Level 2 is when they are perpendicular, and level three is when they are anything else. We will learn these levels in class.

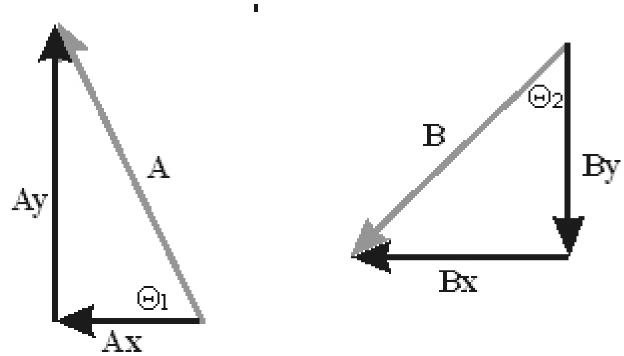
Homework: Read 3-1 to 3-3, Questions 1-12, Problems 1-18

Physics 30A - Class #5 Supplement - Adding Any 2 Vectors

Given any 2 vectors, **A** and **B**:



You can add them by first resolving them into their perpendicular components: A_x, A_y, B_x, and B_y.



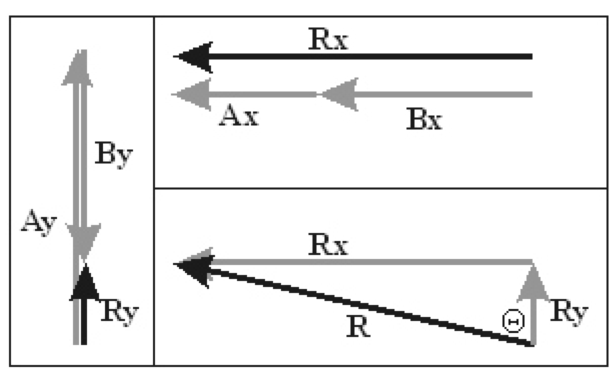
Keeping track of directions is easier with positives and negatives, so make horizontal vectors (x) be positive if they point east, and negative if they point west. Similarly make vertical vectors (y) be positive if they point north, and negative if south. Using this convention, we don't have to say N/E/S/W for x and y vectors.

$A_x = A\cos(\theta_1)$ Manual check: $\mathbf{A_x}$ is negative (west)
$A_y = A\sin(\theta_1)$ Manual check: $\mathbf{A_y}$ is positive (north)
$B_x = B\sin(\theta_2)$ Manual check: $\mathbf{B_x}$ is negative (west)
$B_y = B\cos(\theta_2)$ Manual check: $\mathbf{B_y}$ is negative (south)

Note that the choice for sin and cos depends on the vectors - always think of SOHCAHTOA

These 4 vectors are all parallel or perpendicular to each other. First add the parallel vectors to find the components of the resultant vector: R_x and R_y, where

$\mathbf{R_x} = \mathbf{A_x} + \mathbf{B_x}$ $\mathbf{R_y} = \mathbf{A_y} + \mathbf{B_y}$



Add these vectors the way any two perpendicular vectors are added.

$R = \sqrt{R_x^2 + R_y^2}$ from Pythagoras.

And $\theta = \tan^{-1}\frac{R_x}{R_y}$ from SOHCAHTOA

Vector **R** is the sum of $\mathbf{R_x}$ and $\mathbf{R_y}$, which also makes it the sum of the original vectors **B** and **A** as shown here:
$\mathbf{R} = (\mathbf{R_x}) + (\mathbf{R_y}) = (\mathbf{A_x} + \mathbf{B_x}) + (\mathbf{A_y} + \mathbf{B_y}) = (\mathbf{A_x} + \mathbf{A_y}) + (\mathbf{B_x} + \mathbf{B_y}) = \mathbf{A} + \mathbf{B}$ so we're done!

Physics 30A - Class #6

This Class: 3-4

Now that we know how to mathematically work with vectors, we can use them to do physics. We will start by working with velocities and displacements.

Displacements can be added as vectors to get the total displacement. This is really quite simple, if you can add vectors. Typically, you are given two (or more) individual displacements, and asked to find the total displacement - by adding them.

Velocities are a little more complicated. Realize that the velocity of an object is always made relative to some coordinate system, which is usually attached to an object (such as the earth). This object then automatically has a velocity of zero with respect to (wrt) this chosen coordinate system.

It is often convenient to keep track of velocities with a pair of subscripts, where the first subscript represents the object of which the velocity is being measured, and the second subscript represents the object the velocity is made relative to. For example, if a car is moving at 30 m/s, then this could be symbolized by $\mathbf{v}_{CE}$ (the velocity of the car, wrt the earth (assumed unless otherwise stated). Other examples include $\mathbf{v}_{BW}$ (velocity of a boat wrt the water) and $\mathbf{v}_{PA}$ (velocity of a plane wrt the air. You should make it clear what the subscripts you choose stand for, if it is not obvious - do this by stating what the letters stand for ("s" = shore, for example).

It is sometimes useful to reverse the roles of the two objects, in which case $\mathbf{v}_{AB} = -\mathbf{v}_{BA}$ (where A and B are any two objects). For example: if a car moves at 50 m/s to the east: $\mathbf{v}_{CE}$ = 50 m/s [E] (where "C" = car and "E" = earth) then $\mathbf{v}_{EC}$ = -(50 m/s [E]) = 50 m/s [W] ... the earth moves at 50 m/s, west wrt to the car - so a passenger in that car can claim that they are at rest, while the world rolls past them at 50 m/s to the west.

Finally, to change the frame of reference to a new frame, all you need to do is add the velocity of the old frame of reference relative to the new frame of reference - consider an example: A person walks at 1 m/s east relative to the boat they are on. The boat moves at 5 m/s east, relative to shore. How fast is the person going, relative to shore? $\mathbf{v}_{PB}$ = 1 m/s [E] $\mathbf{v}_{BS}$ = 5 m/s [E] Then $\mathbf{v}_{PB} + \mathbf{v}_{BS} = \mathbf{v}_{PS}$ = 6 m/s [E].

A useful trick in the above addition of relative velocities is to notice how the "inside pair of subscripts" seem to cancel - leaving the "outer pair" remaining. This only works if the inside pair are the same thing (B for boat, in this case)

Homework: Read 3-4, Questions 1-12, Problems 19-33

Physics 30A - Class #7

This Class: 3-5 and 3-6

A projectile is any object that is freely moving through the air. We are going to work under the simplified conditions where air resistance continues to be something we will ignore. Furthermore, our projectiles will be influenced only by gravity - so balls, arrows and bullets (after thrown or shot) can be considered to be projectiles until they hit the ground. Rockets, airplanes, parachutists and frisbees are not considered projectiles, as they are not freely moving through the air - they are either powered, or have air effects that should not be ignored.

Projectile motion is really quite simple if you are good with the kinematics and vectors that we have already studied. Consider the motion of a projectile as being two distinctly separate "component" motions. If a ball is thrown up at some angle, such as when it is thrown to someone, then realize the ball goes up, then down - and simultaneously moves sideways.

Treating these two motions separately, we can analyze the Y motion (vertical) as being no different than what we have already seen - the kinematics all applies - the only change being the initially, the ball was going at a velocity that is the Y-component of the thrown velocity (this means you have to resolve the velocity according to the given speed and direction). Vertically, gravity still results in an acceleration of 9.8 m/s^2 down (regardless of whether the ball was thrown fast or slow, and also regardless of the angle it was projected at.

The X motion (horizontal) is different than the Y motion. Horizontally, there is nothing making the projectile speed up or slow down (remember that we are choosing to ignore air resistance). This means that horizontally the projectile travels with a constant speed - the horizontal component of the original velocity.

The path that a projectile takes through the air is called the <u>trajectory</u>. Constant horizontal motion and simultaneous accelerated vertical motion results in the trajectory being <u>parabolic</u>.

There is one new formula that is relevant for projectile motion - the Range Formula, which only applies to projectiles that are launched from - and land at - the <u>same vertical level</u>. Under this condition, the <u>range</u> (horizontal distance covered) can be found from $R = \frac{v^2 \sin(2\theta)}{g}$ which I will derive in class. Of particular interest in this equation is the mathematical suggestion that the optimal angle for a projectile, to maximize the range is 45° - which is easily confirmed by experimentation.

Homework: Read 3-5 and 3-6, Questions 13-15, Problems 34-48

Physics 30A - Class #8

This Class: 4-1 to 4-6

We now leave our study of kinematics, to enter dynamics - which explores how things get moving, or change their motion.

Central to the study of dynamics is the concept of force. A force can be described as any push or pull. Much of what we will study is the result of the work of Sir Isaac Newton, arguably the most brilliant person who has ever lived. Newton clarified the physics of dynamics with what we now refer to as "Newton's Laws of Motion" of which there are three, referred to simply as "Newton's First Law", second law, and third law.

Prior to Newton, it was believed that an object must have a force applied to keep it moving. This is a very reasonable conclusion to make, as it seems to be true everywhere we look - if the push is removed, things stop. For example: a moving car is moving because of the engine producing a force - if the engine is shut off while the car is moving, the car will soon stop. Galileo challenged this idea, with a simple thought experiment: he argued that if an object is pushed to slide on a surface, it will travel some distance, and then stop. If a smoother surface is used, it will travel further before it stops. If an even smoother surface is used, it will travel further still. He concluded that if a perfectly smooth surface could be made, then the object should go for ever. Force then was not needed to keep an object moving - but is needed to counter the non-ideal conditions we have available to us (friction etc).

Newton formalized Galileo's findings in what we now call Newton's First Law - which can be stated as "an object will have a constant velocity unless there is a net force acting on it". First let's clear up the "net" in "net force". Force is a vector, and the phrase "net force" means "vector sum of all forces acting on an object". We abbreviate force with $\mathbf{F}$ and net force as $\Sigma\mathbf{F}$. Newton's first law is typically used in one of two ways: if you ever have an object moving with constant velocity, then you can conclude that there is no net force on it. Conversely, if you are told (or determine) that there is no net force on an object, then you can conclude that it must be moving with constant velocity. Realize in all of this that "constant velocity" may also mean being at rest (constant velocity of zero). Of course if an object is not moving with constant velocity, then we describe it as accelerating, and conclude that there must be a net force responsible.

Newton's Second Law makes the above numerical. It can be said in words: "An object's acceleration is proportional to the net force acting on it, and inversely proportional to the object's mass". This is simply saying that an object will accelerate - the amount of acceleration depending on the net force (how hard it is being pushed) as well as on the object's mass (massive things are harder to accelerate). This can also be said in equation form: $\mathbf{a} = \Sigma\mathbf{F} / m$ or more commonly (solve for $\Sigma\mathbf{F}$) $\Sigma\mathbf{F} = m\mathbf{a}$. Remember that we must have mass in kilograms, and acceleration in m/s^s. What unit will result for F in the above equation? Answer: $kg{\cdot}m/s^2$ of course. This unit is kind of clumsy, so we invent a new unit, which we call a newton (N) to represent exactly that - so one newton is defined to be a $kg{\cdot}m/s^2$. A more familiar unit of force is the pound. It may be helpful to know that a pound is the same thing as about 4.45 newtons. (1 lb = 4.45 N).

Newton's Third Law is the most confusing of the three. It is popularly known as "for every action there is an equal and opposite reaction" - I hate this because it tells you nothing. My version of Newton's third law is $\mathbf{F}_{12} = -\mathbf{F}_{21}$ in which the first subscript for a force tells which object is exerting the force, and the second subscript is for the object that is having the force applied to. We will talk much more about this in class.

Homework: Read 4-1 to 4-6, Questions 1-12, Problems 1-8

Physics 30A - Class #9

This Class: 5-1, 5-2, 5-4

We have already studied motion in a straight line, as well as the motion of a projectile. Now we look at another important type of motion: simple harmonic motion (SHM for short). The word "harmonic" in SHM suggests "repeating" and so we are studying the type of motion in which an object moves in a regularly repeating manner.

First some language:

cycle - is a word used to describe the motion which gets completed over and over again. as an example, consider a grandfather clock's pendulum which swings back and forth. The back and forth motion can be called a cycle.

period - is the amount of time required for one cycle to occur. Symbolize period with "T". The pendulum of a grandfather clock has T = 1s. In general T = amount of time / # of cycles that occur in that time.

frequency - is a measure of how often (frequently) the motion is repeated. frequency with "f". The pendulum of a grandfather clock has f = 1 cycle / second - or 1 Hertz (Hz). In general f =# of cycles that occur / amount of time. Note that frequency and period are reciprocals of each other: f = 1/T and T = 1 / f.

The first type of SHM we will focus on is that of uniform circular motion (UCM). UCM is motion in which an object moves with constant speed (uniformly) around a circular path. A cycle for this motion consists of going "once around". The speed of an object in UCM can be described as v = d /t as usual, but this equation may take a new form, if the motion for exactly one cycle is considered. For one cycle, d is the distance around the circle = circumference, so d = 2πr, and the time for this to occur is exactly one cycle, so t = T. Substitution gives us the following:

For an object in Uniform Circular Motion: $v = \frac{2\pi r}{T}$ or v = 2πrf (since f = 1/T)

Notice that event though the speed of an object in UCM is constant, its velocity (which includes direction, and is always tangential to the circle) is always changing. This means that objects in UCM are accelerating (yes, you can accelerate without changing your speed!) The acceleration is always directed toward the center of the circle, and so is called a centripetal (meaning "center seeking") acceleration. A common mistake is to think that the acceleration is directed outward, or "centrifugally" (meaning "center fleeing").

Your textbook gives a derivation for the following, and I will show it in class, but the result is that an object in UCM is accelerating centripetally (a_c) at a rate of:

$a_c = \frac{v^2}{r}$ or subbing in the above expressions for v: $a_c = \frac{4\pi^2 r}{T^2}$ and $a_c = 4\pi^2 r f^2$

Newton's second Law can be used at this point to describe the forces involved. The key idea here is that there is really nothing new going on except that the acceleration is a specific type of acceleration: a *centripetal* one. We give the same description to the net force: we call it a centripetal force.

For an object in UCM F_{net} is called F_c and so $F_c = \Sigma F = ma_c$

There are some common problem types you should be aware of:

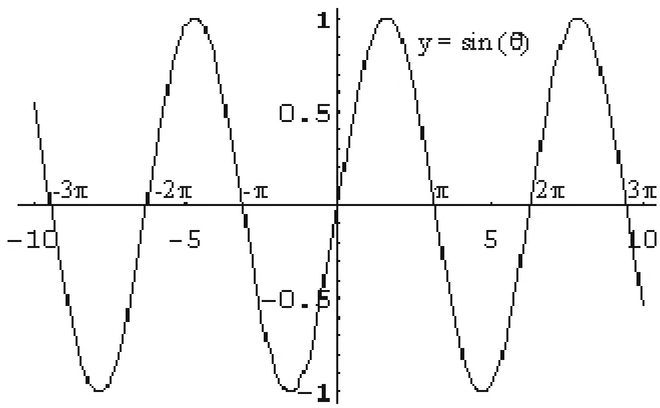
1. For an car driving in UCM on a flat road, the sum of all forces reduces to only friction
2. For a car driving on a banked curve at the “design speed” (no friction), the sum of all forces reduces to the inward component of the normal force: $F_N \sin\theta$ which leads to $\tan\theta = v^2/(rg)$
3. For a satellite orbiting a planet, there is only one force, and so the sum of all forces reduces to the inward pull of gravity.

Homework: Read 5-1, 5-2 and 5-4, Questions 1-5, Problems 1-16

Physics 30A - Class #10

This Class: 11-1, 11-4

I lied last class - but it was for your own good. Uniform circular motion (UCM) is a very good example of a motion that repeats itself in a “simple” way. Strictly speaking, however, it is not an example of simple harmonic motion. The actual criteria for SHM is that the motion be sinusoidal - the **d**-t graph of the motion should look like a sine curve.



Here is a graph of y=sin(θ). If we think of this being a d-t graph, then the object is going “back and forth” regularly. We call the maximum displacement the amplitude (this is d = 1 in this example).

The essential criteria for SHM is that an object must have a net force that always pushes it to one location (called the equilibrium position where there is no net force). This restoring force (because it acts to restore it to that position) must be proportional to the distance from the equilibrium position (ie $F_{restoring} \propto d$)

An excellent example of true SHM is the back and forth oscillation of a mass attached to a spring. First we need to look at springs:

Springs have what we can call a “natural length” - this is the length of the spring when it is relaxed. A spring stretched or compressed exert forces in the direction that “restores” it back to its natural length. Furthermore, the spring exerts a force that increases linearly as the stretch / compression increases (in other words the force is proportional to the stretch / compression). This is described by the equation known as Hooke’s Law (named after physicist Robert Hooke): **F** = -k**x** where **F** is the force exerted by a spring (or other springy material such as a rubber band), **x** is the amount of stretch or compression, and k is called the “spring constant” which is constant for a given spring, but different from one spring to another - it measures how stiff a spring is (larger k = stiffer spring). Note that the negative sign can be ignored if calculating the magnitude of the force only.

A mass that is pulled away from the equilibrium position and then let go will have a net force acting on it, in the direction towards the equilibrium position. Once it gets to the equilibrium position it will have picked up speed, and although have no net force on it there, will “shoot past” it, at which point the restoring force slows it down, stops it and the process repeats. The period for a mass bobbing up and down on a spring is found with $T_{spring}=2\pi\sqrt{\frac{m}{k}}$. Note that for such a mass, it will have a maximum velocity as it shoots through the equilibrium position, and zero velocity at the extreme ends. It will have an acceleration of zero at the equilibrium position (no net force there) and a maximum acceleration that is a maximum when at the extreme points (restoring force strongest there). Interestingly the amplitude does not affect the period.

The other example of SHM is a pendulum. The pendulum is not true SHM, but very close to it if the angle the string makes is small. The corresponding equation is $T_{pendulum}=2\pi\sqrt{\frac{l}{g}}$ where l is the length of the pendulum. Interestingly the mass of the “bob” does not affect the period.

Homework: Read 11-1, 11-4, Ch 11: Questions1-4, Problems 1-4, 12, 14 (a-c), 23-25

Physics 30A - Class #11

This Class: 5-5 & 5-6

Here we have a closer look at the force of gravity. So far we know that gravity is a force that a planet such as earth exerts on an object: $F_G = mg$ where g is the "acceleration due to gravity". $g = 9.8\ m/s^2$ on earth: all objects (regardless of mass) would have this acceleration if earth's gravity was the only force (and therefore the net force) acting on it.

While standing on earth you are pulled "down" by its gravitational force. For convenience, imagine you are standing on the north pole. What would happen if space aliens came along and magically made the entire southern hemisphere disappear - in particular would you still be pulled down by gravity, or would the force of gravity vanish, leaving you to float above the remaining half of earth? The intuitive answer (to me) is that I should still have a force of gravity pulling me down, though perhaps not as strong.

The aliens find that they need more of the earth, and so they remove the "lower" half of what remains - again ask if gravity for you should still be present. Repeat this as many times as you like ... until you are standing on a mere boulder size piece of the former earth: does gravity still pull you to that boulder? The only significant difference between it and the original earth is size (and therefore mass). It seems unavoidable that you would still be pulled "down" or "towards" that boulder. Continue the above until you are standing "on" a mere speck of dust - science of the very small - you are still pulled towards that speck of dust.

Newton realized that earth is basically a big rock, and since there is a force of attraction between it and other objects, he reasoned that there must be a force of attraction between all bits of matter. Furthermore he reasoned that since the mass of the smaller object plays a role in how strong the force is ($F_G = m_{object}g$ so $F_G \propto m_{object}$) then the mass of the object should be no different ($F_G \propto m_{planet}$). Thinking the "object" and the "planet" as two objects (so what if one is more massive than the other) Newton concludes that $F_G \propto m_1m_2$.

Newton realized that the distance between the two objects must also play a role, since for example we don't notice a strong attraction to distant planets, moons, etc. Newton knew that the moon was a distance from the earth of about 60 earth radii away - and that it orbits the earth with a period of just under a month. Based on this, Newton concluded that it is moving in circular motion - with the only force acting to cause this motion being the force of gravity earth pulls on it. This means that the moon should have a centripetal acceleration of "g" which would not be 9.8 but rather some smaller value, since the moon is further than we are (we are a distance of 1 earth radius from the center of the earth). A simple calculation reveals that the moon has an acceleration around earth of about 1/3600 of the surface value of g = 9.8 - the conclusion is that the force of gravity grows weaker with the <u>square of the distance</u> between the objects, so $F_G \propto 1/d^2$. Including what we said earlier, we see $F_G \propto m_1m_2/d^2$. To turn a proportionality into an equation, a "constant of proportionality" is needed: we use the letter G, and call it the "Universal gravitational constant" so that $F_G = Gm_1m_2/d^2$.

Newton didn't know the value of G - it was determined later by Henry Cavendish by measuring values of m_1, m_2, d and F_G between two lead balls - the difficulty is that F_G very weak unless at least one of the masses is quite large (as in a planet).

Universal Law of Gravitation: $F_G = \dfrac{Gm_1m_2}{d^2}$ note: $g = \dfrac{Gm_{planet}}{d^2}$ where $G = 6.67 \times 10^{-11}\ N{\cdot}m^2/kg^2$

As soon as a value of G was determined, it became possible to determine the mass of the planet earth (the radius was already known approximately). Modern values for earth (which you should memorize) are:

$m_{earth} = 5.98 \times 10^{24}$ kg $r_{earth} = 6.38 \times 10^6$ m

Homework: Read 5-5 to 5-7, 5-10 Questions 6 - 8, Problems 21 - 33

Physics 30A - Class #12

This Class: 5-7 to 5-10

Now that we know all about gravity and circular motion we can put them together. A satellite is an object that moves around another object (typically a planet or star) - examples of which include the moon which is a satellite around earth, and the earth which is a satellite around the sun. The orbital trajectories are approximately circular, and so we can apply the physics of circular motion to satellites.

The moon is attracted to the earth - so why doesn't it fall into the earth? The answer is that the moon is falling - but falling means accelerating downward - there are two distinctly different ways this can happen: it could pick up speed as it gets closer to the earth (which means it would hit earth) or it could move in a circular path and have this acceleration be centripetal (so the speed is nearly constant, and the distance between earth and moon doesn't change much on the long term). The physical criteria for a satellite to orbit in a circular path is that the satellite must move fast enough so as to have its centripetal acceleration match that of the gravitational acceleration at that location (remember g changes with elevation)

Recall that $a_c = \frac{v^2}{r}$ and that $g = \frac{Gm_{planet}}{r^2}$ conclusion: for a satellite $\frac{v^2}{r} = \frac{Gm_{planet}}{r^2}$

Suppose the shuttle is in orbit near the Hubble space telescope - which orbits the earth at an altitude of about 596 km. The astronauts float around "weightless" but are they really weightless? Calculate the mass of a 100 kg astronaut on the surface of earth - and then in the shuttle as described.

Homework: Read 5-5 to 5-7, 5-10 Questions 9 - 15, Problems 34 - 41

Physics 30A - Class #13

This Class: 6-1 to 6-6

Energy is a central concept in physics - in fact physics could be defined as "the study of how matter and energy interact with each other" - it's amazing we have made it this far without talking about it! Energy itself is very hard to give a definition for - a dictionary defines it as a "vigorous action, the capacity for action, the capacity for performing work, usable power (as heat or electricity)" etc. Of these, the part that most closely defines the physics in the word energy is the "capacity for performing work" - in fact my definition of the word energy would be the "ability to do work".

"Work" has a very precise definition in physics. It is NOT simply an "effort". Rather, work is what is achieved when a force acts over some distance. Mathematically, we can define work for a constant force as $W = F_{\parallel}d$ where $F_{\parallel}$ is the component of the force that is parallel to the displacement. It is more convenient to write this as $W = Fd\cos\theta$ where θ is the angle in between the force (still assumed constant) and the direction of motion. The unit of work, as seen from the equation would be the newton-meter (N·m) which is given the special name "joule" (J) in honor of James Prescott Joule.

$W = Fd\cos\theta$ unit of work is the joule (J)

Note that we can speak of the total work done (in which case the net force should be used in place of F in the equation) or the work done by one specific force (work done *by you* for example) - in which case specific forces should be used. Furthermore note that work is a scalar (no direction) - it can be positive or negative in the traditional sense of "more than zero" or "less than zero".

If the force is not constant, then the work may be estimated (or calculus may be used) by the use of a Force (parallel) - distance graph. $W = F_{\parallel}d$ and so is the area (product) under the graph. A special thing to notice is that the force causing uniform circular motion (F_c) does no work: the force is always changing (in direction) but is always perpendicular to the motion so $F_{\parallel} = 0$.

Although essentially a circular definition, it is useful to define work as the transfer of energy: doing work is the process of giving energy while doing negative work is the process of removing energy. Where does the energy you have transferred go? The answer is that it depends: there are many different forms of energy.

If the work done was used to make a stationary object move, then that moving object now has the ability to do work (it could hit something and exert a force over a distance). We call the energy of motion kinetic energy (K) (note that your book uses "KE" which I don't like). The derivation is in your book - the result is that kinetic energy of a moving object can be found as $K = \frac{1}{2}mv^2$.

The work-energy theorem is a direct consequence of the above: it states that the net work done on something is equal to the change in its kinetic energy. This is useful in that no matter what happens: if an object does not speed up or slow down, then no work was done on it (example: uniform circular motion).

Just as kinetic energy is the energy of motion, we can define potential energy to be the energy of position. An object may have energy simply based on its location. The most common example of this is the position of a mass in a gravitational field (a gravitational field is anywhere there is the influence of gravity, and is measured by the value of g). The "higher" up an object is, the more potential energy it has. The symbol for potential energy is U and gravitational potential energy is $U_G = mgh$ where "h" is the height above some arbitrary reference level (it is your choice where this level is - "ground level" is often used, but you may choose different levels if more convenient).

You can think of potential energy as the energy "that is stored, waiting to be released". Other examples of potential energy are chemical potential energy (batteries, explosives and donuts have lots of this), and nuclear potential energy (uranium and plutonium have lots of this).

Another important example of potential energy is the energy that can be stored in a spring. We term the potential energy of a spring that is not in its relaxed state elastic potential energy, and can symbolize it as U_S (S for spring). $U_S = \frac{1}{2}kx^2$ (recall that k is the "spring constant" and x is the degree of the stretch / compression).

Note that potential energy exists only for conservative forces. A conservative force is one that "conserves" (or "preserves") the energy in a usable, returnable manner: the energy put into lifting an object is easily returned by dropping it; the energy put into stretching a spring is returned by releasing it etc. Conservative forces have the important property that the work done by a conservative force is independent of the path taken - only the overall displacement matters. As an example, the same work is done in lifting an object one meter, compared to lifting the same object two meters, then lowering it one meter (both have the same displacement, and the path traveled does not play a role in the work done). Friction, on the other hand is a typical non-conservative force. Friction can do a lot of (negative) work if an object is dragged back and forth, even if the displacement is small or zero. We can generalize the work-energy theorem as $W_{tot} = \Delta K$

Homework: Read 6-1 to 6-6, Questions 1 - 10, Problems 1 - 32 omit 15

Physics 30A - Class #14

This Class: 6-7 to 6-10

The Law of Conservation of Energy simply says that energy cannot be created or destroyed. The law of conservation of energy can be written in equation form as $energy_{final} = energy_{initial} + W$ this should make perfect sense as the "energy you end up with is the same as the energy you started with, plus any amount of work done - since work is a transfer of energy."

The concept of "mechanical energy" (M.E.) is useful here: we define M.E. to be the sum of kinetic energy (K) and potential energy (U). M.E. = K + U. The Law of Conservation of Energy can then be written as $M.E._f = M.E._i + W$ for situations in which there are only potential and kinetic energies.

It is important to realize that although energy is conserved, it can change from one form to another. We have already seen two forms of energy: kinetic and potential. Recall that kinetic energy is the energy of motion while potential energy is the energy of position (and can be gravitational, elastic, etc). Additional forms of energy include thermal (the energy of "warmth" - we will learn more about this in 42A physics), light, sound, nuclear and chemical (these last two may be considered a type of potential energy).

An example of how energy is conserved though changes forms would be in throwing a ball up in the air, and letting it hit the ground. The beginning of this example goes as far back as the sun - where there is a tremendous amount of nuclear energy being changed into thermal and light energy. Some of the sun's light energy arrives at earth, and is absorbed by plants, and converted into chemical energy (sugars etc). Animals may eat these plants, use some of it, and store the rest of it (fats, proteins etc). The person who threw the ball ate food (chemical energy) and used some of it to do work in throwing the ball - giving it kinetic energy. The ball climbed up, slowing down as it does so (it is losing kinetic energy to gravitational potential energy). At the highest point it has no kinetic energy, but substantial potential energy. It falls down reversing the transfer back from potential to kinetic energy. It hits the ground, which does negative work to the ball (removing the energy). When energy seems to disappear, the most likely place to find it is in thermal energy: the act of catching the ball has transferred the energy into warmth - the ball has warmed the ground (ever so slightly) on impact.

Power is simply the rate at which work gets done: $P = W/t$. Since work is a transfer of energy, we may also think of power as being the rate at which energy gets transferred: $P = \Delta energy / time$. The units of power are joules per second, which is given the special name Watt (W) in honor of James Watt. Note that a non-SI unit of power that is still in use is the horsepower (hp) - 1 hp = 746 W

Homework: Read 6-7 to 6-10, Questions 11 - 25, Problems 33 - 56

Physics 30A - Class #15

This Class: Chapter 7

We now change our focus to another important concept in physics: momentum. Newton originally used the term to describe what he called the "quantity of motion" that an object possessed. By quantity of motion, you must realize that there are only two factors: (1) mass of what is moving, and (2) the velocity of the motion (note that since velocity is a vector, so will be momentum).

> $\mathbf{p} = m\mathbf{v}$ ($\mathbf{p}$ = momentum, m = mass, $\mathbf{v}$ = velocity)
> Units of momentum: kg·m/s, which we call a kg·m/s (there is no single name for this unit, but it is equivalent to a N·s since N = kg·m/s^2.

The reason that the concept of momentum is important is because it is a conserved quantity. The Law of Conservation of Momentum states that momentum cannot be created nor destroyed (but is frequently exchanged between objects).

We can "prove" the law of conservation of momentum based on Newton's 3rd Law. Every force is an interaction between two objects. This "pair of forces" can change the momentum of both objects. $\Delta p = m\Delta v$. But since F = ma, and a = Δv / t - solve for Δv = at. This means that Δp = mat = Ft. In words, the momentum change of an object is the product of force and time. Newton's 3rd Law states that while this happened, the *other object* had the exact same force, but opposite in direction (which would have been for the same length of time). This means that both objects changed their momentums by equal amounts, but in opposite directions .... the total change in momentum was zero.

> $\mathbf{p}_f = \mathbf{p}_i$ This is the Law of Conservation of Momentum. Note that sometimes momentum is "lost" or "gained" to/from objects outside of our interest. We call this an exchange of momentum with the environment.

Newton in fact studied momentum before he investigated force. We have said in the past that ΣF = ma, and said that this was Newton's 2nd Law. Newton in fact never wrote this. Newton originally described a force as something that can change the momentum of an object. In fact, he stated that a force is the "rate of change" of the momentum it can cause. So $\Sigma F = \Delta p / t$ is the original form of Newton's 2nd Law. (You can show that $\Delta p / t = ma$).

One important application of momentum, is in the analysis of collisions. Since momentum is always conserved, we can apply the law of conservation of momentum to the collision. Note that collisions may take place in 1, 2 or 3 dimensions. In these cases, we can state that $\mathbf{p}_f = \mathbf{p}_i$ in each dimension (in the X, Y and Z).

Furthermore, we categorize collisions as being either elastic (for collisionis in which kinetic energy is also conserved), or inelastic (for collisions in which at least some of the kinetic energy is lost to other forms). Note that real collisions tend to be inelastic. The extreme case of inelastic is termed "perfectly inelastic" which occurs when the colliding objects STICK together (note that kinetic energy need not be entirely lost).

A related quantity is that of impulse (**J**). Impulse is simply the name given to the act of a force acting over some time interval.

> $\mathbf{J} = \mathbf{F}t$; $\mathbf{J} = \Delta\mathbf{p}$ (note that this is often expressed simply as $\mathbf{F}t = \Delta\mathbf{p}$

Finally, note that we have always up until now treated objects as if they were "point particles" - we have always disregarded the actual size or shape of objects. Mathematically, we can take "extended bodies" (real life objects that have actual shape and size) and treat them as if they were points, provided we put that point at the location known as the centre of mass. This point can be found experimentally, or mathematically for simple shapes (it is at the geometric centre for symmetrical objects).

Homework: Read Chapter 7 (all) Do all Questions & Problems!

Physics 30A - Class #16

This Class: 10-1, 10-2 & 10-6

We now sadly turn to the last chapter of 30A physics: Fluids. Note that in addition to the sections listed above, we will be looking at sections 10-7 to 10-9. The remaining sections of chapter 10 are not in the AP curriculum.

"Fluid" is the name given to any material that can flow. Essentially, this means that fluids are what we normally consider to be gases and liquids. It is crucial to recognize fluids (and indeed all matter) to be made up of tiny particles (atoms or molecules normally). Over large distances, each of these particles exerts no significant forces on each other. When very close to each other, these particles repel each other quite strongly due to electrical repulsions of the like-charge electron clouds. In between these two extremes, the particles exert fairly strong attractive forces on each other, due to the presence of opposite charges. The bottom line is this: left to themselves, these particles would tend to "clump" with each other, with some "equilibrium" distance of separation.

This is essentially the makeup of a solid: the particles are held tightly to each other, maintaining this equilibrium distance. If forced closer, the repulsion grows, trying to push them further apart; if pulled apart, the attraction tries to pull them back together. As long as the applied forces are not too great, the solid will maintain its shape.

Mind you, the particles themselves are always in motion due to their thermal (ie kinetic) energy - the hotter the temperature, the more rapidly they move. A solid may be melted into a liquid if it is raised to a sufficient temperature. This is nicely explained as the increased motion of the particles may be violent enough to break the electrical bonds holding it relatively fixed in place. These particles are then free to roam about the bulk of the material as they are not held tightly in place. Note however that the bonds are not gone, they are instead perpetually being reformed and broken. On the average, the particles still maintain an equilibrium distance with each other. For this reason, both solids and liquids are said to be incompressible which is a bit of an exaggeration: the reality is that they both are able to be compressed, but negligibly so unless tremendous forces are available.

Heat a liquid sufficiently and the material will turn into a gas. Here the motion of the particles becomes great enough to break free of the equilibrium distance so that the separation between particles becomes great enough that the particles essentially act independently of each other. Gases are described as being compressible, as the separation between particles is great enough that they are relatively easy to squeeze closer.

Note that in all of this, the particles obey all of the physics we have learned so far. In particular, Newton's Laws continue to be applicable. Truly understand this, and this chapter will make a lot of sense.

The concepts of pressure and density are useful here. Note that although commonly used for fluids, these concepts are not for fluids exclusively. Pressure is a measure of how concentrated a force is. Mathematically, $P = F/A$. Possible confusion: yes, unfortunately, "P" is used for both power and pressure, so you will need to decide what it stands for from the context of the equation ("A" is the area over which the force is being applied). The SI unit of pressure is the N/m^2 which is given the special name "pascal" although kilopascals (kPa) are commonly used. In addition, there are many non-SI units of pressure which (unfortunately) are alive and well, including the pound per square inch (psi), the atmosphere (atm) the bar, and the "millimeter of mercury" (mm Hg).

Density is a measure of how concentrated a mass is. Mathematically, $\rho = m/V$ (the symbol "ρ" is used for density - this is the Greek letter "rho"). The SI unit of density is simply the kg/m^3 which does not have a shorter version. Note that the density of pure liquids and solids is nearly a characteristic value - for example, the density of water (which you should now memorize) is 1000 kg/m^3. Also note that chemistry does not use SI units; in chemistry the density of water would usually be expressed as 1 g/cm^3. Specific Gravity (SG) is sometimes used in place of density. SG is simply the ratio of a substance's density to the density of water (at 4°C): $SG_{substance} = \rho_{substance}/\rho_{water}$. The SG of water is 1 by definition.

Pressure In Fluids: For a fluid sitting at equilibrium, every particle is in equilibrium, which means that there is no net force on any particle. If there was a net force, that particle would accelerate, as it is free to flow. But every particle below the surface has particles above it, each of which has a certain weight. This translates to a downward force on each particle which is directed downward, due to the weight of the particles above. Yet there must be no net force, so we conclude that the particles below are supporting it with an upward force. Instead of this thought on a particle by particle view, consider a small horizontal surface sitting in the fluid: it must be pushed down by the fluid above it. This downward push is equal to the weight of the fluid above the surface: $F_G = mg$. Divide both sides by the area of the imagined surface: $F_G/A = mg/A$. Now realize that the "m" here is the mass of fluid above the surface, which would be a column of fluid which is "h" high (alternatively, think of "h" as being the depth of the surface). This column would have a volume $V = Ah$, and since $\rho = m/V \rightarrow m = \rho V = \rho Ah$. Substitute this in place of m in the above: $F_G/A = (\rho Ah)g/A$ which becomes $P = \rho gh$ ... the pressure inside the fluid is proportional to each of density, g and depth.

$P = \rho gh$ (Pressure within fluid, ρ = density (assumed constant), h = depth in fluid

An important detail that is easily misunderstood: although pressure is technically a vector, the pressure *within a fluid* is a scalar. The pressure is simply there, of a certain amount - the pressure in the fluid is not pointing in any direction. This changes when you consider an object within the fluid: at the surface of the object, the force the fluid exerts is necessarily perpendicular to the surface, if the fluid continues to be at equilibrium. If this were not the case, then by Newton's 3rd Law, the object would push back on the fluid at some other angle, which would have to result in an acceleration - which is not happening if the fluid is in equilibrium. This is true regardless of the orientation of the object and even if the object is curved (the force is perpendicular to it at each point).

Fluids can exert buoyant forces on objects immersed within them. Recall that the pressure within a fluid depends on the depth within the fluid: $P = \rho gh$. An object in the fluid (consider a simply shaped one, such as a cube that is level in the fluid) will have a force exerted on it from the fluid from all around it. Horizontally, there will be a perfect cancellation. Vertically however, there will be only a partial cancellation as the upward force will be greater than the downward force (because the lower end is deeper than the upper end). In fact, the net force from the fluid which is F_B will be (using up as postive) $F_B = F_{up} + (-F_{down})$. Say that the upper end is at a depth H, and so the bottom end is at a depth H+H' (H' = the height of the cube). $F_{up} = P_{lower\ end}A = \rho g(H+H')A$; $F_{down} = P_{upper\ end}A = \rho gHA$. So $F_B = \rho g(H+H')A - \rho gHA = \rho gHA + \rho gH'A - \rho gHA = \rho gH'A$ but H'A is the volume of the cube (and so the volume of the "displaced fluid") so $F_B = \rho gV$ .... but ρV is the mass of the fluid that has been displaced so $F_B = mg$ which is of course the weight of the fluid that has been displaced. This is known as Archimedes' Principle.

Considering that an object immersed in a fluid also has its own weight, the net force on the object will be the sum of the upward buoyant force, and the downward force of gravity. Clearly an object will float in a fluid only if the fluid is more dense than the object. Objects will sink in fluids that are less dense than they are. "Neutral buoyancy" is the term used to describe the critical situation in which a fluid has the same density as an object immersed in it - in such a case the object will not float or sink - it will sit in a neutral state with no net force acting on it.

Homework: Read 10-1, 10-2 and 10-6
Questions 1 - 19 omit 17
Problems 1-9, 11, 19-29

Physics 30A - Class #17

This Class: 10-7 to 10-9

Alas, the time has come - this is the *last* class handout for 30A physics - believe me, you're nowhere near as happy as I am about this. I'm happy because next semester, I get to do this whole thing all over again!

To remind you of an important fact: fluids are materials that can flow. Gosh, I guess we should get to the flowing part. Hydrodynamics is the study of fluids in motion (hydrostatics was the subject of the previous handout).

We classify the type of fluid motion as being either laminar (also known as streamline) and turbulent. We will focus on laminar flow, but you need to know the difference between the two, which is that in laminar flow, the particles of the fluid follow "smooth" paths. This means that each particle of the fluid will follow a unique path that does not cross the path of other particles of the fluid. Furthermore, the motion of each particle is completely predictable, as each particle completely follows the path of the particle ahead of it. Turbulent flow on the other hand, is less (if at all) predictable. Motion pathways cross over and vary with time. Eddies are found in turbulent flow, which are small swirling pathways that significantly hinder the flow of the fluid. From this point on, we will consider only laminar flow.

The rate at which a fluid flows in a pipe (etc) is termed "mass flow rate" which can be thought of as the amount of water current. There is no official symbol for mass flow rate, though it is mathematically described by $\Delta m/t$ (it is the number of kilograms of fluid that flow past a fixed point per second). Notice that $\Delta m/t = \Delta(\rho V)/t$ and if we consider incompressible fluids (constant ρ) then $\Delta m/t = \rho\ \Delta V/t$. If the pipe is cylindrical (so that $V = Al$) then $\Delta m/t = \rho\ \Delta(Al)/t$. Furthermore, if the cross sectional area (A) of the pipe is uniform, then $\Delta(Al)$ is really $A\Delta l$, and so $\Delta m/t = \rho\ A\delta l/t$. Of course l/t is velocity. This means that $\Delta m/t = \rho\ Av$.

If the pipe is not leaky and doesn't branch out, then the mass flow rate must be the same everywhere throughout the pipe. Choosing two locations "1" and "2", it must therefore be the case that $A_1v_1 = A_2v_2$ (remember, we are assuming an incompressible fluid, so $\rho_1 = \rho_2$) This is known as the equation of continuity - which basically says that fluids have to be moving fastest through the narrowest part of a pipe.

For an idealized fluid (which would have no viscosity) the energy carried by the fluid would not be lost. Recall that during laminar flow, the pathways the particles take do not cross. Consider a chain of particles making up one such pathway. Not all of the particles need to be going the same speed, nor do they have to be at the same height, so the potential energy (mgh) and the kinetic energy ($\frac{1}{2}mv^2$) can be varying. Before you jump to the conclusion that the mechanical energy of each particle must be the same, realize that there is also the possibility for one particle to do work on an adjacent particle - transferring energy to (or from) it. This transferred energy would be $W = Fd = (PA)d = P(Ad) = PV$. Since the total energy is conserved, it must be the case that $U_G + K + W = \text{constant}$. So $mgh + \frac{1}{2}mv^2 + PV$ is constant throughout the fluid. This equation is more commonly written in a different version, obtained by dividing by V throughout: $mgh/V + \frac{1}{2}mv^2/V + PV/V = \text{constant}$ which, remembering that $\rho = m/V$ becomes $\rho gh + \frac{1}{2}\rho v^2 + P = \text{constant}$. This is Bernoulli's equation. (Note that a "y" is often used in place of "h")

A well known special case of Bernoulli's equation is for a fluid that flows in a pipe that does not change it's height. The equation can then be contracted to $\frac{1}{2}\rho v^2 + P = \text{constant}$. Since we are dealing with incompressible fluids, the counterintuitive fact is that any increase in velocity is accompanied by a decrease in pressure - this alone is known as Bernoulli's Principle.

Homework: Read 10-7 to 10-9 Questions 20-23, 26-29 Problems 30-37