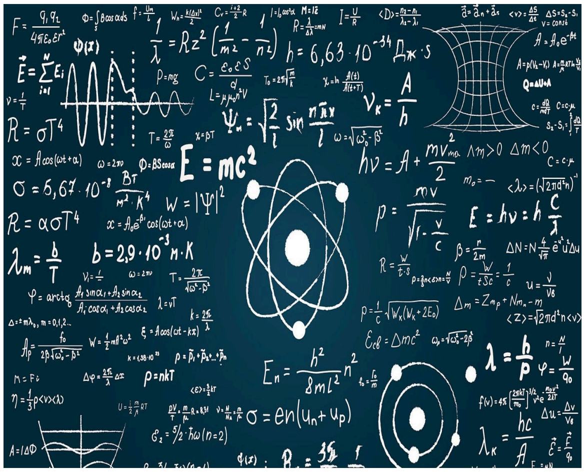
Welcome to AP Physics!



IMPORTANT
Please read this document in its entirety as it will be expected of you on your first day of class to have completed all tasks and be familiar with the material presented. You must submit the Unit Guide via Google classroom by September 8th, 2025. There will be two assessments the first two weeks of school. The first Assessment will be on Chapter 1 (date TBA) the first week of school. The second assessment will be on Chapter 2 (date TBA) the second week of school.

AP Physics is a rigorous course equivalent to a semester of college level physics - both lecture and lab. Because of the rapid pace of work and analysis, our primary emphasis is on developing an understanding of unifying concepts that connect the major topics of mechanics and energy .By confronting complex physical situations or scenarios, the course is designed to enable students to develop the ability to reason about physical phenomena using important science practices, such as explaining relationships, applying and justifying the use of mathematical routines, designing experiments, analyzing data, and making connections across multiple topics within the course.

The AP Physics curriculum centers around five "Big Ideas". You will need to learn basic underlying concepts but, more importantly, you must understand how they all relate in order to explain and analyze more complex systems. You **MUST** focus on analytical thinking and applications in order to see the big picture after you are taught the basic concepts:

- **Big Idea 1** – Objects and systems have properties such as mass and charge. Systems may have internal structure.
- **Big Idea 2** – Fields existing in space can be used to explain interactions.
- **Big Idea 3** – The interactions of an object with other objects can be described by forces.
- **Big Idea 4** – Interactions between systems can result in changes in those systems.
- **Big Idea 5** – Changes that occur as a result of interactions are constrained by conservation laws.

These four big ideas are the framework for the eight main units of the course:

1. **Kinematics**
2. **Force and Translational Dynamics**
3. **Work, Energy, and Power**
4. **Linear Momentum**
5. **Torque and Rotational Dynamics**
6. **Energy and Momentum of Rotating Systems**
7. **Oscillations**
8. **Fluids**

In addition to the course content organized into the eight units listed, College Board define three science practices that students should develop and apply over the span of the course:

1. **Creating Representations**
2. **Mathematical Routines**
3. **Scientific Questioning and Argumentation**

Refer to the AP Physics Course and Exam Description published by the College Board for more details about the framework of the course and the exam AP Physics 1

The Physics curriculum encompasses a wide range of topics and mathematical procedures. What does this mean? *We are always short on time!* To ensure your success on the AP exam in May, we will dive right in on day one! **To make sure you are ready to go on the first day of class, you have tasks to complete over the summer.** Much of this is a review of material you previously learned in your previous math classes. We will only briefly review this material in class and you can expect an assessment on these topics the first week of school.

Task 1: Introductory letter. Tell me about yourself. Compose your letter and submit via Google Classroom on "Welcome Letter" assignment prior to the first day of school. (You will receive a notification in the summer once the classroom is created) In your letter please include the following information:

1. Introduce yourself.
   - What is your name?
   - Do you have a nickname you go by?
   - What grade are you in?
2. Courses:
   - What science classes have you taken so far?
   - How many AP classes have you taken before this year?
   - What subject area(s) are you most interested in continuing in college?
   - Is there anything that you've especially liked or disliked about your earlier physics/science classes?
3. Yourself
   - What do you like to do (hobbies, sports, music, interests, etc.)?
   - Tell me about your family (siblings, pets, who do you live with? how would you describe them?)
   - Do you have a job or plan on getting a job next year? What kind of job?
4. Learning
   - What are your personal strengths when it comes to learning new material?
   - What causes you to struggle in a course? How do you address that challenge?
   - How would you describe yourself as a learner? How would you describe yourself as a team or group member?
5. AP Physics
   - Why are you taking this course? What do you hope to accomplish/gain from this course?
   - What are you looking forward to most in AP Physics? Do you have any concerns coming into AP Physics this year?

Task 2: Read and completing the Summer Package Notes (Appendix A)

- **Chapter 0: Intro to the Course**
  - Introductory lesson to the course and expectations in the class
- **Chapter 1: Mathematics Review**
  - Review of mathematical concepts and procedures
- **Chapter 2: One-Dimensional Kinematics**
  - First Half of Unit 1 covering displacement, velocity, and acceleration
    - **Topic 1.1: Scalars and Vectors in One Dimension**
    - **Topic 1.2: Displacement, Velcoirt, and Acceleration**
    - **Topic 1.3: Representing Motion**

Note - we will be using College Physics for the AP Physics 1 and 2 Courses (Third Edition) by Stewart/Freedman/Ruskell/Kesten as our textbook during the year. You can pick up a hard copy of this text from the main office over the summer. We will set you up with access to the e-text once classes begin

Task 3: Time to get familiar with the science practices listed above.

Watch all assigned videos listed below:

Chapter 1

What is Physics?
Significant Figures
Metric System
Scalars and Vectors

Chapter 2

Defining Motion
Graphing Motion
Kinematic Equations
Free Fall

Task 4: Complete Summer Assignment #1 (Appendix B)

- Use a different color text to complete.
- The assignment will be posted to our summer Google Classroom at a later date and is to be submitted there by 8 AM on the second day of classes, September 8, 2025.

The textbook chapters/sections associated with this Assignment is:

- **Chapter 1: Introduction to Physics**

Task 5: Complete Summer Assignment #2 (Appendix C)

- Use a different color text to complete.
- The assignment will be posted to our summer Google Classroom at a later date and is to be submitted there by 8 AM on the second day of classes, September 8, 2025.

The textbook chapters/sections associated with this Assignment is:

- **Chapter 2: Linear Motion**

Task 5: Statistics & Graphing

As part of the AP Physics curriculum, students must employ the use of some analytical math (statistics and probability) and graphing skills. Throughout the year we will practice these quantitative skills. You may use an "Equations and Formulas" sheet, provided by the College Board in class and on the AP exam in May. Please print a copy of this formula sheet (attached **Appendix D**) for frequent use in class.

There are multiple types of graphs you must be able to interpret and/or construct (see science practice 1 in the CED). On the AP exam, you will have to construct graphs to show relationships between variables and

quantities. Here are a couple of documents to help you get comfortable in choosing the type of graph to construct. Please download copies for yourself.
HHMI Plot Selection Tool
Graph Choice Chart

Task 6: You should familiarize yourself with using Google Sheets to organize data, perform basic calculations, calculate standard errors, statistically compare data sets, and create and interpret graphs. We will frequently use Google Sheets to perform these tasks in class. Please watch the video below to familiarize yourself with basic foundational tools.

https://www.youtube.com/watch?v=iAWll1g0s74

Complete this tutorial as a guide to help you with the basics.

https://docs.google.com/spreadsheets/d/1AzzR4Ak2Aq1to2lrUBxNVGfoWA7I3kdohsnuigsw9cI/edit#gid=1940035811

Final Notes:
Please refer to the Syllabus (Appendix E) attached for any questions on the course.

You will receive a notification when our Google classroom is created. Further instructions will be posted there so it will be required of you to check periodically and perform any tasks before the first day of school. Please post any questions or concerns on our stream so that I may answer them for the whole class.

I look forward to meeting you all in September!

Chapter 0 - Welcome!

Chapter Zero?

That's not a typo ... this really is chapter zero. Think of it this way: the "real" material of this Study Guide begins in chapter 1, but there are a few important things that we have to talk about first - hence this chapter that precedes chapter 1. I suppose I could have called this a "preface" but the problem is that pretty much everybody skips reading prefaces, and you really don't want to skip this important (though strangely numbered) chapter.

About this Book

The purpose of this book is to help you - a student in AP Physics 1 - achieve an *actual understanding of physics*. You really can't fake that by the way. Well you can try, but the AP exam will almost certainly destroy you if you don't really "get" physics.

Who Wrote These Notes?

Allow me to introduce myself: my name is Barry Panas. I am a high school physics teacher in Winnipeg, Canada (Earth). I have been teaching high school physics (including AP Physics) for over 20 years. I have taught in both public and private schools and have also taught university courses. I have provided training on AP Physics to hundreds of physics teachers through full day workshops and week long Summer Institutes throughout Canada, The US, Hong Kong, and Taiwan. I have also graded AP Physics exams in the US for the Educational Testing Service (ETS).

Physics is much more than a job to me. It is something that I'm passionate about, and in some ways it's kind of a hobby too. I actually really, really like physics! Hopefully my love of physics will come through in this book and maybe - just maybe - you will come to like physics too (assuming you don't already).

Of course I recognize that not everybody shares my enthusiasm for physics. Many students take physics only because they need the credit. The fact is that physics is often used at least in part as a "gatekeeper" for programs such as medicine. There are a number of good reasons for this. I assure you that the people who made the decision to have physics as a prerequisite for whatever you are interested in did not do so to make your life miserable (well maybe in part they did - I'm not sure, but there's definitely more to it than just messing with students' lives here).

The fact is that physics really is pretty much everywhere. Sometimes it is front and centre (for example in engineering) and at other times it is a bit off to the side (for example in medicine). I really believe that having a good background in physics will help you no matter what you end up doing. If nothing else, physics is an excellent way to hone your problem solving skills - which is crazy important no matter what you end up doing after this course. Now I suppose that I'm biassed in saying all this, but you can be both biassed and correct at the same time.

In writing these notes, I am not going to make any attempt to hide my personality (you may have noticed already that this doesn't read like a "normal" physics book. Good. I definitely do not want this to be merely another "textbook" - the authors of which generally try to be objective and neutral. Nope - I'm going to try to write this the same way that I talk to actual students when I work with them.

What You Need to Know Before Doing Physics

Chapter 1 introduces (or possibly reviews, depending on your background) some critical material such as units and vectors. Learning actual physics doesn't start until chapter 2. But before any of that, we need to make sure you have the basic, fundamental skills that we *assume* you have already. A lot of people struggle with physics because they struggle with math. Having said that, the math we use in this course is really not all that bad. If you're a bit weak at math, or maybe just rusty from not having used much math lately, it's crazy important that you get your math "up to snuff" as quickly as you can.

Having said that, if you are really good at math, be warned that there is a lot more to physics than "just math". While physics makes regular use of math, learning physics involves learning a lot of ideas, many of which are not at all intuitive. You need to be proficient with math, but know that being good at math is simply not enough to do well in this course.

For some, the remainder of this chapter might be a review, while for others there might be a little (or a lot) of math that you have never seen before. If you find that you need help with any of the material that follows, I encourage you to get some math help as soon as possible. Consider working with a friend, a parent, a tutor, or spend some time on YouTube watching tutorials. Just try to not get too distracted by all of the amazing videos of cats, or whatever you would usually watch for fun (unless you usually watch math tutorial videos).

Here are some basic math skills that you definitely need to be confident with before getting into the material of this course. If you are not comfortable with any of the following, you need to address this immediately. Again - I'm not trying to "teach" this material here, so consider this to be just a quick check to make sure that you're ready to proceed. The answers to these questions appear after the last question - make sure you are getting them right!

Practice Math Questions

Scientific Notation

For starters, you should already know what this means. You should also be able to quickly and easily switch things from "standard notation" (what most people would call "normal") to scientific notation - and back. Here are a few just to make sure:

1) For the following numbers, if given scientific notation, switch to standard notation. If given standard notation, switch to scientific notation:

   a) 2.99×10^{8}　　b) 5.21×10^{-5}　　c) 59800000000　　d) 0.000000123

Using a Calculator

I'm not kidding. You need to *really know* how to use your calculator well. I don't just mean using your calculator for things like "2+3" ... no I'm talking about fairly elaborate calculations that you should be able to enter reliably without "screwing it up". It would be a tragedy If you knew how to do the physics of a problem and then fumbled entering it into your calculator. Especially since your exams are multiple choice. If you get the answer wrong, you get zero for that question - no matter how "close" you were, or how well you did the physics inside the question. And you thought high school was tough!

2. Try the following on your calculator. If you can't get the correct answers then you don't know how to use your calculator! Get somebody to help you ASAP if that's the case! You may round off the answers to 3 figures.

   a) $\dfrac{(6.67\times10^{-11})(5.98\times10^{24})}{(6.38\times10^{6}+2.55\times10^{6})^{2}}$

   Note: Get used to using the bracket buttons on your calculator! They are not always necessary, but in a question like this you really should use them - especially in the denominator (bottom part of the fraction) of this one.

   b) $\dfrac{32.5^{2}\ \sin((3.37)(27.8))}{9.8}$

   Note that your calculator needs to be in "degree mode" whenever you use sin, cos or tan in physics (well at least most of the time ... there are exceptions, but we won't see any for a long time). You can check if your calculator is set up properly getting it to tell you the answer to the sine of 90 degrees. If your calculator gives an answer of "1" then it is set up correctly. If it gives any other answer then you need to switch it to degree mode. If you don't know how to do this, check in the manual or get a calculator savvy person to help you.

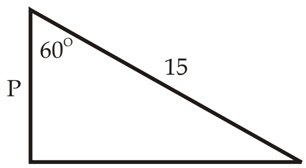
   c) $\dfrac{-5+\sqrt{6.22^{2}-4(8.13)(-2.33)}}{2(4.9)}$

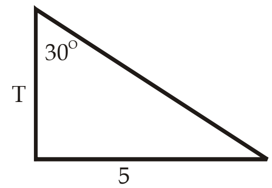
   Note: you should be able to do this in one single calculation, hitting "enter" (or "=") only once at the very end.   Hint: you should be using the bracket buttons!

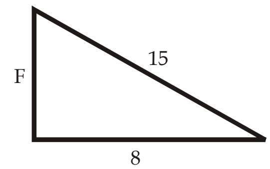
Trigonometry

For our purposes, it is enough that you can work with the Pythagorean relationship ($a^2 + b^2 = c^2$) and trig functions in a right triangle. The following couple of questions will check if you can do these things:

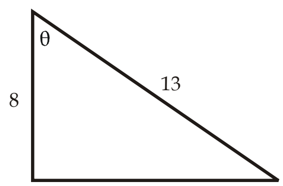
3. Find the size of the side of the triangle labelled with a letter using trigonometry.

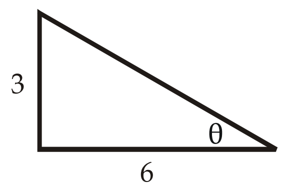
a) 

b) 

c) 

4. Find the size of the angle θ in the following triangles

a) 

b) 

Algebra

We use algebra (equations containing variables) a LOT in physics. If you're rusty in algebra you definitely want to address this before getting into the actual course material.

5. For each of the following equations, solve for the indicated variable.

a) $A = B + C$	(solve for B)	b) $A = \frac{B}{C}$	(Solve for C)
c) $A = B + CD$	(solve for D)	d) $A = (B+C)D$	(solve for C)
e) $A = BC + DE^2$	(solve for D)	f) $A^2 = B^2 + CD$	(solve for B)

Answers to Practice Math Questions

1. a) 299000000 b) 0.0000521 c) 5.98×10^{10} d) 1.23×10^{-7}
2. a) 5.00 b) 108 c) 0.581
3. a) 7.5 b) 8.66 c) 12.7
4. a) 52.0° b) 26.6°
5. a) $B = A - C$ b) $C = \frac{B}{A}$ c) $D = \frac{A-B}{C}$ d) $C = \frac{A}{D} - B$

   e) $D = \frac{A-BC}{E^2}$ d) $B = \pm\sqrt{A^2 - CD}$ Note that this is NOT the same as $B = A - \sqrt{CD}$!

Again - if you did well on the above math questions, then you should be in good shape to get going into the actual course material, beginning with chapter 1. If you had any difficulty with the above, then you really, really , really need to get the math taken care of right now. Work with a friend who is good at math, work with a tutor ... do WHATEVER it takes to get proficient with this math. Chances are good that it'll help you in more places than just physics (much of this same kind of math shows up in other courses too).

How to Do Well in Physics

Let's be honest. Physics has a reputation as being a difficult course. I really think that this is because so many people just flat out take the wrong approach, and end up getting destroyed in the process. You don't want that now, do you? Of course not! Here is some incredibly good advice on how to maximize your likelihood of doing well in this course. I'll tell you right now - there is no "magic" easy way. Thank goodness. If there was, I wouldn't be needed at all.

- **You have to study the ideas presented until you actually *understand* them.** It's not enough to memorize formulas, examples, or anything else. You have to know it well enough to explain the principles you are learning about to somebody else who doesn't yet know physics. If you can teach a physics concept to a ten year old, then congratulations - you understand it. If you cannot, then you don't understand it well enough.

    - **Try hard to "violate" the laws and/or principles you are learning about.** If I say that something "is impossible" try to come up with something that makes you think "ahah - how about in this situation see: it IS possible!" Oh - it's a pretty safe bet that you'll be wrong, but if you can come up with something that seems to suggest that the physics I am teaching you is wrong, then it generally comes down to one of three possibilities:

        1. You have genuinely come up with a violation of an established idea in physics. Congratulations. You should notify the Nobel Committee immediately and start shopping for something snappy to wear on your world tour of presentations you'll be making at universities and on all of the television interviews you will be doing.

        2. You have found an actual problem with the idea that was presented to you due to it being only an approximation or simplification of what is actually an established idea in physics. Congratulations. You weren't "supposed" to catch this, but clearly you've really mastered the idea. Having said this, you should also be able to appreciate why the approximation that was presented here is generally good enough for the situation being described.

        3. You flat out don't understand the idea that was presented. Your "violation" of the idea reveals that you have missed an important idea. Congratulations. You have just discovered a critical misunderstanding and can now take steps to learn the idea more completely.

        By the way - the above possibilities are presented in order of least, to most likely.

    - "Knowing" the ideas is critical - but not enough to do well in this course. **You actually have to PRACTICE BY SOLVING LOTS OF PROBLEMS.** Being good at physics means being a ninja in the ways of Physics. You don't become a ninja by reading books about it. You can't read *"you have to be really, really sneaky"* and say to yourself "right - sneaky - got it! I'm now sneaky and one step closer to becoming a ninja! NO! You have to practice sneaking around!

And its not enough to practice sneaking through the exact same room over and over. When it comes to doing your ninjutsu exam, you are going to be put into a situation you've never been in before, and you will be expected to demonstrate your "sneakiness" (and other ninja skills) by utilizing all of the skill you've developed by sneaking around in all kinds of different environments.

- **Learn the physics continuously throughout the year as the topics are introduced. Don't expect to be able to learn all of this at the last minute before a test or right before the AP exam.** This is a big one, and tragically, it's one that students often fail to buy into until it is too late. If you're in AP Physics, you're probably a generally good student.

  I'm guessing that you've been getting good grades so far, quite possibly without working very hard. I'm telling you now that **you will almost certainly need to put more effort into this course than your most (if not all) of your previous courses.** Don't be overconfident with your ability. If you are right now thinking to yourself *"yeah right, I've heard that before - I know that *I* can put things off until the night before a test and still ace the test"* then please put a big star beside this paragraph, so that later in the year when you realize that you are doing terribly in physics, you will be able to find this paragraph quickly so that you can read it again and say *"I wish I had listened to this advice ... wow - he really does know what he's talking about."*

Good Luck

OK - Hopefully you found this chapter to have something of value in it. A reminder: there was absolutely no physics here so far, and here's a newsflash: there won't be any physics in chapter 1 either (though it does get more focussed on what will be needed for actual physics beginning in chapter 2).

Go find a quiet place free from distractions like friends who'd rather chat than work. Shut your cell phone completely off (don't even put it on "silent" - it'll still distract you). Close the lid of your laptop or put your tablet (and Smart Phone, or really, anything else that will distract you) out of reach - you need to put all your attention to your studies. A little bit of music playing quietly is OK, but if you catch yourself singing along, then it's tugging at your attention too much.

You are lying to yourself if you think you can "multitask" efficiently. You can't. Nobody can. Don't argue with me about that either, it's been proven over and over in study after study. The more your brain is paying attention to incoming texts or a conversation with a friend across the table, the less your brain is capable of paying attention to learning physics (or anything else for that matter). Besides, I'm selfish. I really do want your undivided attention.

> "MULTITASKING" IS A MYTH. IF YOU REALLY WANT TO DO WELL IN YOUR STUDIES, LEARN TO "UNITASK"

Buckle your seatbelt and make sure your helmet is securely fastened because the ride is about to begin. Good Luck!

Chapter 1 - Introduction & Math

There is no “real physics” in this chapter, but resist any temptation you may have to skip it. You really do need to have a good understanding of the introductory material in this chapter before you can successfully tackle “real physics” beginning in chapter 2.

Units

Units are those things at the end of a measurement that make it meaningful by providing a standardized size or amount. If somebody were to describe an object as being “3 long” ... you’d probably raise your eyebrows and wonder what the heck they mean. The question that needs to be addressed is 3 *“whats”* long? Clearly there is a difference between “3 *city blocks* long” versus “3 *pencils* long.” The fact is that “3 long” is pretty useless as it doesn’t include a unit.

While “city blocks” and “pencils” can be thought of as units, both are actually pretty crappy as far as units go. Different city blocks are different in length, as are different pencils, not to mention that the length of any one pencil will shorten as it gets used. What we need are more reliable units - things that are highly standardized and don’t change. There are a LOT of units that have these properties. For length there are inches, miles, centimeters, light years and angstroms (just to name a few). Any one or more of these could be used for any length measurement.

I don’t think it would be an understatement to say that in physics, we are extremely picky about units. Although there are occasional exceptions, for the most part, we insist on a very specific set of units which are known as the “SI” units. In case you care, “SI” stands for “International System” and the abbreviation is “backwards” because it is based on the French name: “Le Système International d'unités”.

Unless you have very good reason to do otherwise (we’ll get there) ... ALWAYS use SI units. Note that this is pretty much a “physics thing”. Neither chemistry nor biology consistently use SI units, so you might have some bad habits to break. In physics, think of “SI Unit” as meaning “Official (for physics) unit.” We’ll be introducing a number of SI units throughout the course, but for now, the following is enough.

IN PHYSICS, YOU MUST DEFAULT TO SI UNITS!

SI Units - MEMORIZE!		
Measurement	**SI Unit (name)**	**SI Unit (abbreviation)**
length	metre (sometimes spelled meter)	m
time	second	s
mass	kilogram	kg

Now is a good time to mention that whenever you see a symbol for anything in physics, you need to use that exact same symbol. Notice for example that the abbreviation for meter above is “m” - that’s a lowercase letter. It would be wrong to abbreviate it as a capital letter “M”. We are very picky about these things, but for good reason - often a lower case letter means something different than the same letter in upper case! Oh yeah - also, the official SI abbreviation for second is “s” ... not “sec”.

Metric Prefixes

In general, a prefix is something that can be attached to the beginning of a word to alter its meaning. A good non-physics example of a prefix is "anti" which generally means "opposite" or "against". Thus "antivenom" is something that opposes the effects of venom and an "antivirus" program helps get rid of computer viruses.

The above examples of prefixes are not quite the kind of prefixes we really need to talk about though. There are a bunch of prefixes that have been developed specifically to refer to numbers. In particular, "SI prefixes" (also known as "metric prefixes") indicate powers of ten. There are a lot of metric prefixes - the ones in the chart below are just a few of them, but truth be told these are the ones that tend to get used in intro physics, so these should be good enough.

SI Prefixes - MEMORIZE!		
Prefix name	**Prefix abbreviation**	**Power of ten equivalent**
giga	G	$\times 10^{9}$
mega	M	$\times 10^{6}$
kilo	k	$\times 10^{3}$
centi	c	$\times 10^{-2}$
milli	m	$\times 10^{-3}$
micro	μ	$\times 10^{-6}$
nano	n	$\times 10^{-9}$

Again - do NOT change any of the symbols that you come across! Notice for example that an upper-case "M" stands for mega, while a lowercase "m" stands for milli. By the way - the symbol "μ" is the Greek letter "mu".

Now the thing to know about these prefixes is that they can be attached to the front of any unit. There are a few cases of these prefixes that you are almost certainly familiar with, but you may have not stopped to really think about it. As an example, consider the "centimeter" (cm). A centimetre is literally a "centi" metre, in which centi refers to " $\times 10^{-2}$" which means 1/100. In other words, a centimetre is literally a hundredth of a metre. But "centi" doesn't belong to metres. In the exact same way (though less commonly used) a cs (centisecond) is a hundredth of a second and a cg (centigram) is a hundredth of a gram. Similarly, a "kilogram" is a "kilo" gram, which is to say " $\times 10^{3}$" grams or 1000 grams, just as km is 1000 m and a ks is 1000 s.

Notice that the SI (official physics) unit for length is the metre. This means that kilometres, centimetres and millimetres (etc.) are not SI units. Generally, if we are given any of these, we need to first *convert* these other measures into the SI unit: the metre. Similarly the second is the SI unit for time - not the minute, hour or day (etc.). It's a bit of a strange case, but notice that it is indeed the kilogram (not the gram!) That is the SI unit for mass. Yes - this means that if we are given a mass in grams, we MUST convert it to kilograms.

Converting Units

A particularly important skill you will need to have in this course is that of converting units. This means that if you are given a measurement in one unit, you are able to "switch it" to the corresponding measurement in a different unit. Often this means taking a measurement that is not in SI units, and converting it into SI units, but there are occasions when it is necessary to go the other way.

Unit conversions are done by taking the measurement you want to convert and multiplying it by one or more "conversion factors". A conversion factor is nothing more than a fraction that has the following special property: the top and bottom parts of the fraction MUST be equal to each other. For example, since one minute is equal to 60 seconds (i.e. 1 min = 60 s), the fractions $\frac{1\text{min}}{60s}$ and $\frac{60s}{1\text{min}}$ may both be described as being conversion factors.

CONVERSION FACTORS ARE SIMPLY FRACTIONS IN WHICH THE "TOP" (NUMERATOR) AND "BOTTOM" (DENOMINATOR) ARE EQUAL TO EACH OTHER.

The "trick" is in choosing the correct conversion factor(s). This is easy once you realize that units can be treated just like variables as far as the math goes. For example, units can "cancel" just like an "x" in math. Here's an example to show what I mean by this:

The expression $\frac{5x^2y}{xy}$ can be simplified by "cancelling" the y's and also reducing the x^2 to an x in the top part: $\frac{5x^2y}{xy}=5x$. Units work the *exact same way*. This means that for example $\frac{5\text{min}^2 kg}{\text{min}\cdot kg}=5\text{min}$.

UNITS CAN "CANCEL" JUST LIKE X'S (AND OTHER LETTERS)

So choosing a conversion factor basically involves ensuring that the units you want "show up" while the original units "cancel". Here is a trivial example. Suppose we need to convert two minutes into seconds. Yes, I know you already know the answer to this. It's 120 seconds. That's not the point! The point is to show how to do this conversion properly, so that you can keep using this method for harder conversions that you won't be able to do in your head. Here we go:

We are given the amount 2 min. In this measurement, the unit is minutes, abbreviated "min". We don't want minutes. We want to convert this into a different unit: seconds, abbreviated "s". We do know that one minute is the same as 60 seconds, so we have two possible conversion factors: $\frac{1\text{min}}{60s}$ and $\frac{60s}{1\text{min}}$. Suppose we try to multiply our measurement by the first of these. If we did, this is how it would go:

$$2\min\left(\frac{1\min}{60s}\right)=\frac{2\min^2}{60s}=\frac{1}{30}\frac{\min^2}{s}$$

which is NOT a meaningful conversion at all. The undesired unit of minutes is not gone at all, and the desired unit of seconds is not in the right spot (it should not be in the bottom of a fraction).

Now consider multiplying 2 minutes by the other conversion factor:

$$2\min\left(\frac{60s}{1\min}\right)=2(60)s=120s$$

Note how the unit of minutes actually "cancels" out, leaving the desired unit right where we want it.

Here's another unit conversion example. Suppose we are given a speed of "75 miles per hour" (i.e. 75 mi/h) which we are to convert into "m/s". Now don't worry - you don't need to memorize conversions involving non-metric units, so let me help by providing the following information: a mile is abbreviated as "mi" and 1 mi = 1609 m (at least to the nearest metre). Also note that each hour consists of 60 minutes, each of which has 60 seconds. This means that one hour is the same as 60×60 = 3600 seconds; i.e. 1h = 3600 s.

Beginning with the measurement provided: $75\frac{mi}{h}$ notice that miles is in the numerator, so we're going to need to cancel it by introducing miles in the lower part of a conversion factor. Similarly, since we have hours in the denominator, we need to introduce another hour in a numerator to cancel it. This is how it all plays out:

$$75\frac{mi}{h}\left(\frac{1609m}{1mi}\right)\left(\frac{1h}{3600s}\right)=33.521\frac{m}{s}\ \ or\ \ 33.5m/s$$

Again - notice how in this conversion the undesired units of miles and hours mathematically cancel out, and the desired units are introduced by the conversion factors.

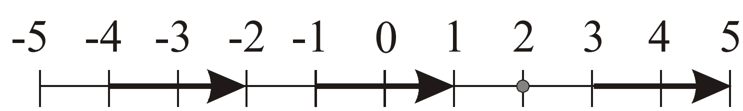
Scalars and Vectors

At first glance, this might seem intimidating, but it's really not at all that bad. Although it may be an unfamiliar word, you are already very familiar with scalars as they are what most people would simply regard as "normal" numbers. In fact, it's hard to even describe what we mean by "scalar" unless we compare them to another kind of number: a vector.

So here's the deal: a scalar is a number that only has one part, and that one part tells only one thing: size (or more impressive sounding: "magnitude" which just means size). It's kind of tricky to get past how mind-blowingly obvious this. Think about it: what is the difference between the (scalar) numbers 1 and 1000? Well, 1 is "small" and 1000 is "big" (at least compared to each other). That's it. 1 is a scalar and so is 1000. Each of these scalar numbers does only one thing: they tell us "how big" or "how much". Again this seems obvious (and it is), but let's now have a look at vectors.

Unlike scalars, vectors have two parts. They also have a magnitude (size) part, and that part looks exactly like a regular old scalar. However, they also have a *direction*. The direction can be revealed in many different ways. One way is with an actual word such as "right" or "north" or "down". This means that while "2" is a scalar (it only has one part: magnitude), "2 to the right" is a vector (it has both magnitude and direction).

Now the overwhelming temptation here is to think of "2 to the right" as a "number" *and* a direction. Nope. Don't do that. You have to think of "2 to the right" as being a number ... a vector number. Let's further demonstrate the difference between the scalar "2" and the vector "2 to the right" by using a number line:



On a number line, scalars are indicated by very specific *points*. The scalar number "2" exists at only one place, and that one place is indicated above by the small grey circle. There is nowhere else on the number line that has that same value. In fact, every unique point on a number line is a unique scalar number.

By comparison, vectors cannot be seen as points on a number line. Instead, vectors are drawn as *arrows*. These vector arrows have two parts: a magnitude (length of the arrow) and a direction (as shown by the arrow head). There are 3 arrows shown on the above number line, but here's the neat part: each one of them represents the vector "2 to the right" equally well. It doesn't matter where the arrow is located. Vectors are not points on a number line - they are arrows with length (magnitude) and direction.

SCALARS CAN BE DRAWN AS **POINTS** ON A NUMBER LINE; VECTORS CAN BE DRAWN AS **ARROWS**

Symbols for Vectors

To avoid confusion between vectors and scalars, it is often desirable to use a special notation for vectors and scalars. Both vectors and scalars are typically symbolized as letters (though not always letters from "our" alphabet ... Greek letters are particularly common also). However, to make the symbols for vectors look different from the symbols for scalars, one of two things are typically done:

- Symbols for vectors can be shown in "**bold**" font while scalars are not bold. This is especially common in word processed text such as this one. Here are a couple of examples:
  - b = 4.5 (in which b is a scalar)
  - π = 3.14 (in which π is a scalar)
  - **F** = 8 [north] (in which F is a vector)
  - **g** = 9.8 [down] (in which g is a vector)

- Symbols for vectors can be drawn with a special "arrow symbol" placed on top of the letter. This is especially common when writing by hand. The arrow symbol is sometimes a "normal arrow" like this: "→" but often an arrow with only half of the arrow head drawn like this: "⇀". Here are a couple of examples:
  - $\vec{F}$ = 8 [north] (in which F is a vector)
  - $\vec{g}$ = 9.8 [down] (in which g is a vector)

SYMBOLS FOR VECTORS ARE EITHER TYPED IN **BOLD** OR PRINTED WITH A SMALL ARROW (⇀) ON TOP.

Depending on the situation, I'll sometimes signify vectors by using the bolded letters, and other times I'll use the small arrow symbol. Both are acceptable.

Vector Directions

Direction is an essential part of a vector. There are many different ways that the direction of a vector can be stated, but I'm going to stick with just three basic ways. The first way to state the direction of a vector is with a word or words. We tend to only do this for vectors that point in really nice directions. For the most part, this means one of the following six directions: north, east, south, west, up and down. When one of these six "nice" directions are used, we usually put them in square brackets. For example: 5 [down] or 25 [west].

When vectors point in one of the six "nice" directions, it is often much more useful to use positive and negative to give the direction. To do this, it's first necessary to state which direction you want to use as the "positive" direction. For example, let's say that there are two vectors: F_1 has a magnitude of 5 and points north while vector F_2 has a magnitude of 12 and points south. Here is how we can state these vectors in words:

$\mathbf{F_1}$ = 5 [North] $\mathbf{F_2}$ = 12 [South]

But here is another way we can describe these same two vectors:

North is + $\mathbf{F_1} = +5$ $\mathbf{F_2} = -12$

And here is yet another way we could describe them:

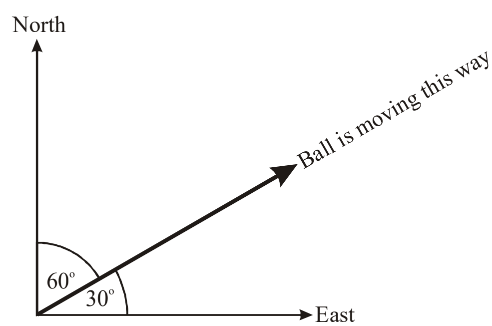
South is + $\mathbf{F_1} = -5$ $\mathbf{F_2} = +12$

Resist any temptation of asking whether $\mathbf{F_1}$ is "really positive" or "really negative". It is in fact "really north" and all three of the above say exactly that. The positive and negative signs for vectors only mean something in conjunction with the stated reference direction.

STATING AND THEN USING A REFERENCE DIRECTION (E.G. "UP IS +") IS CRAZY IMPORTANT!

For vectors that are in "awkward" directions (i.e. somewhere between the 6 "nice" directions), we have to use a different approach to describe their direction. For us it will be enough to recognize that some vectors are horizontal, and we need to state exactly which way they are pointing in terms of north, south, east and west, while other vectors are not horizontal, and we need to describe how far from being horizontal they are (though at that point we usually don't worry about which way they are pointing in terms of north, east, south and west).

Consider a ball that has been kicked and is now rolling on the ground. It might be moving exactly north, or exactly east, but it might also be moving somewhere between these two directions. Consider the following diagram showing the direction that the ball is moving in (the diagram shows how things would look if seen from a high point, looking down - a so called "bird's eye view" or more simply "as seen from above").



Clearly the ball is not moving exactly north, and it's not moving exactly east either. You might be tempted to say something like "north-east" but if anything, that would imply exactly half way between north and east which is not the case here (plus we tend to not use that kind of description for direction in physics).

To describe the direction of the ball's motion, we prefer to use angles (in degrees) and compass directions to further identify the direction. There are always two different ways that this can be done. For the above direction, here they are:

- 60° east of north (correct)
- 30° north of east (also correct)

Again - *both* of the above are correct, though we would typically only use one of them (either one will do).

The problem is that students often botch this part up. Consider the following two attempts to describe the same direction, both of which are not correct!

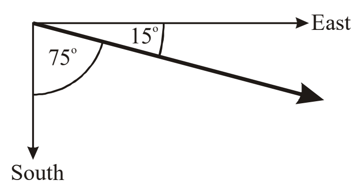
- 60° north of east (incorrect)
- 30° east of north (also incorrect)

Clearly the *order of the compass directions* (north and east here) make a difference, and which is correct also depends on which angle is used. How is a student supposed to know which is correct?

The answer comes from noticing that each of the indicated angles (60° and 30°) connects the vector to *one* of the compass directions (the 60° angle connects the vector to north while the 30° angle connects the vector to east). Here is the rule:

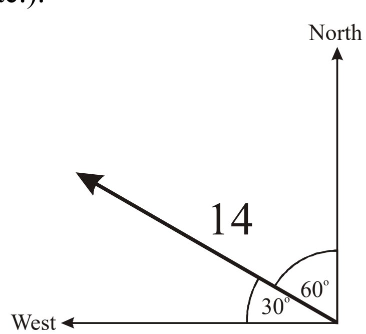
THE COMPASS DIRECTION THAT THE ANGLE IS CONNECTED TO ALWAYS GETS LISTED LAST.

Here is another example:



The direction of this vector can be given as either 15° south of east *or* 75° east of south.

Vectors in awkward directions are often stated by first giving the magnitude of the vector, and then the direction, using the "@" symbol (which we read as "at" ... just like in email addresses). Consider one last example, this time using the magnitude of the vector as well as the direction. Oh yeah - we sometimes abbreviate the directions (N for north, etc.).



This vector can be stated as either 14 @ 60° W of N *or* 14 @ 30° N of W.

Up and Down

OK - all of the above works great for vectors that are horizontal. Sometimes we are more interested in vectors that are not horizontal. If the vector points up or down, then great - we can just say so, such as

f = 2.5 [up]   **g** = 9.8 [down]

or even better - we can use a reference to positive, such as

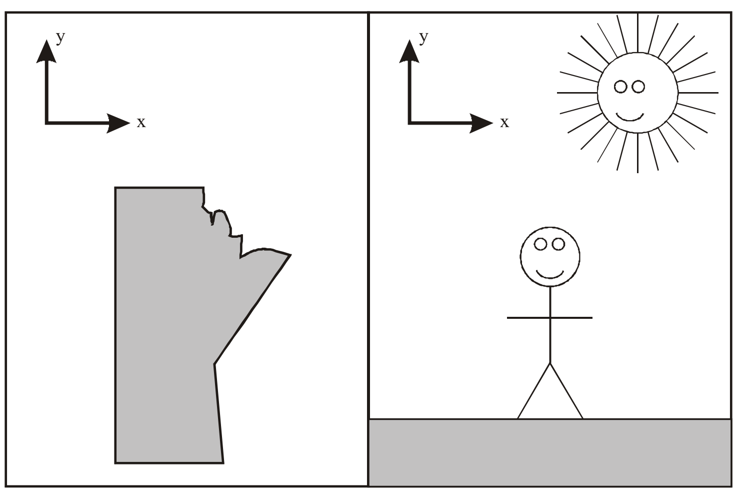
up = +   **f** = +2.5   **g** = -9.8

But what about those pesky vectors that are somewhere between the horizontal and the vertical? Note that *none* of north / east / south / west are of any help here ... those directions are all horizontal. This is actually a bit of a confusion to a lot of people, so here's something to particularly make note of:

UP IS NOT THE SAME AS NORTH; DOWN IS NOT THE SAME AS SOUTH

Think about it: if you want to go visit Santa Claus and Polar Bears, you have to head *north*. If you instead head "up" you will never get to Santa's house, but you will eventually enter the clouds, and if you keep going that way, you'll eventually get to "outer space" (though I actually don't like that term).

The fact is that sometimes people confuse up and north (and also confuse south with down). This is probably because of the way we draw diagrams. Consider the following two diagrams:



OK fine - I never claimed to be an artist, but I'm rather proud of these diagrams - I did draw them myself! But I didn't draw them to impress you with my computer graphics ability - there is a very important physics lesson to be learned from these diagrams.

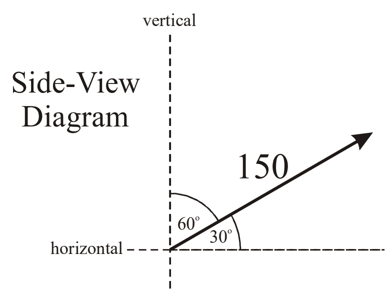
The diagram on the left is a map of Manitoba, Canada. In this diagram, it is implied (though not stated) that the direction labelled as "y" is north, and the direction labelled "x" is east. Meanwhile, the diagram on the right of a stick-person (how's that for not being sexist? Shame on you if you that it was a stick *man!* Though in this case you would have actually been correct ... his name is Stan) standing on the ground. It is again not stated, and yet hopefully clearly implied that the direction labelled as "y" is *not north* but rather up. As for x in the right side diagram, I really have no idea which way that is. It *might* be east, but that would only really be the case if Stan is facing south (take a moment and see if you can really get a good 3-dimensional understanding of why that is true). Mind you, the direction labelled "x" could just as easily be north, which would be the case if Stan is facing east. Again - try to wrap your head around that, 3-dimensionally.

The diagram on the left is basically a view from above, with a pretty standardized orientation of using "towards the top of the page" as north. In such a diagram we can actually be very certain of where north, east, south and west are ... and we also can tell where "down" is (it is directly *into* the page) as well as "up" (it is pointing *out of* the page).

The diagram on the right by contrast is a "side view". The only directions we can be certain of are up (which is towards the top of the page) and down (which is towards the bottom of the page). We have no idea about any other direction, and so we typically refer to them merely as "left" and "right" - which is from our point of view, looking at the diagram.

> BE CAREFUL NOT TO CONFUSE "NORTH" WITH "UP" - WHEN YOU DRAW A DIAGRAM (OR LOOK AT A GIVEN DIAGRAM) ALWAYS GIVE SOME THOUGHT AS TO WHETHER THE DIAGRAM IS A VIEW FROM ABOVE (I.E. "TOP VIEW") OR A VIEW FROM THE SIDE (I.E. "SIDE VIEW").

Now that we've got that cleared up, how do we identify vectors that are not horizontal? There is more than one way, but the most common is to simply indicate the angle that the vector makes to the "horizontal". This can be clearly seen in a side-view diagram, like this:



This vector can be identified as being

150 @ 30° above the horizontal *or* 150 @ 60° from the vertical

We really have no clue as to which way the above vector is pointing in terms of north, south, east, or west – and that's OK. In situations like this, we are often happy with just being clear about horizontal and vertical.

Adding Vectors

The fact that vectors are so different from scalars means that the math of vectors is different from that of scalars. One skill in particular that we will need to access pretty early on is how to add vectors. When adding vectors, I like to think of there being three distinct scenarios which are based on the orientation of the two vectors. In the first (and simplest) case, the two vectors point in the exact same direction (which is sometimes described as being "parallel"), or exact opposite directions (which may be described as being "antiparallel"). In the second case, the two vectors are perpendicular to each other and in the third (and most complicated) case, the two vectors are in any other orientation (I sometimes call this the "ugly" scenario).

Case 1: Adding Parallel or Antiparallel Vectors

We *love* adding vectors that are in the exact same direction (which is what is meant by "parallel" in the case of vectors). It's really, really easy. All you have to do is add their magnitudes (sizes). The sum of the two vectors (which is sometimes called the "resultant" vector) will have the exact same direction as the vectors you started with. This is as easy as it gets. In case it's not clear, a few examples should do the trick:

e.g. $\boldsymbol{A}$ *= 3 [North]* $\boldsymbol{B}$ *= 4 [North] Find* $\boldsymbol{R} = \boldsymbol{A} + \boldsymbol{B}$

Since the two vectors **A** and **B** point in the same direction (i.e. they are parallel), we can find the size of the resultant by adding their magnitudes. This means that the size of **R** is 3 + 4 = 7.

Also, since the vectors both point north, then the answer (resultant) must also point north. This means that the answer is **R** = 7 [North]

e.g. $v_1 = 12$ *[up]* $v_2 = 8$ *[up] Find* $\mathbf{R} = v_1 + v_2$

Again: being parallel, the resultant is just the sum of the magnitudes, and has the same direction. This means that **R** = 20 [up]

Adding vectors that point in the *opposite direction* (i.e. "antiparallel") is just as easy, but you need to remember that it is a little different. When vectors are in the opposite direction, you simply subtract the magnitudes (larger subtract smaller so that the answer itself is positive) ... and then use the direction of the larger vector. Again - examples may help:

e.g. $\boldsymbol{A}$ *= 3 [North]* $\boldsymbol{B}$ *= 4 [South] Find* $\boldsymbol{R} = \boldsymbol{A} + \boldsymbol{B}$

Since the two vectors **A** and **B** point in the opposite direction (i.e. they are antiparallel), we can find the size of the resultant by subtracting their magnitudes (larger subtract smaller). This means that the size of **R** is 4 - 3 = 1.

Also, since the larger vector (**B**) points south, then the answer (resultant) must also point south. This means that the answer is **R** = 1 [South]

e.g. $v_1 = 12$ *[up]* $v_2 = 8$ *[down] Find* $\mathbf{R} = v_1 + v_2$

Again: being antiparallel, the resultant is just the difference of the magnitudes, and has the same direction as the larger. This means that **R** = 4 [up]

ADD PARALLEL VECTORS (SAME DIRECTION) BY ADDING THEIR MAGNITUDES AND STICKING WITH THE SAME DIRECTION; ADD ANTIPARALLEL VECTORS (OPPOSITE DIRECTION) BY SUBTRACTING THEIR MAGNITUDES AND STICKING WITH THE DIRECTION OF THE LARGER.

Case 2: Adding Perpendicular Vectors

This is NOT hard, but does take more of an effort than the parallel / antiparallel cases. The key to adding perpendicular vectors is to draw the correct vector diagram. To do this, you have to "chain" the vectors together so that the arrows make a path. Think of it this way: you start somewhere (it doesn't matter where). You then "move through" the first vector arrow in the direction that it is pointing. Once you have arrived at its arrowhead, you then enter into the back of the next arrow and again "move through" it leading to its arrow head.

Note that a correct vector addition diagram always has the vectors attached to each other "tip to tail" ... the arrow tip of the first vector connects to the back (tail) of the next vector.

Once you have the two vectors drawn correctly, you then draw a third vector: the resultant vector. This is the vector that takes a "shortcut" directly from the starting point to the ending point as revealed by the vectors being added.

Note that the resultant vector has a magnitude (length) that can be found by the Pythagorean relationship ($a^2 + b^2 = c^2$). The direction of the resultant can be found with trigonometry (inverse tangent in particular).

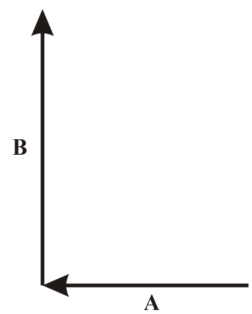
The following example should help clear this up:

e.g. ***A*** *= 3 [West]* ***B*** *= 4 [North]* *Find* ***R = A + B***

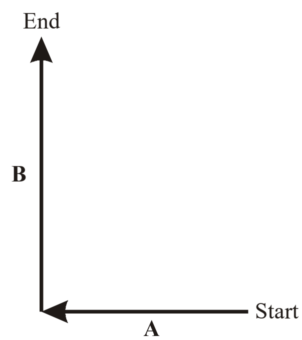
The first thing we do is draw the first vector, which in this case is **A**. Since we are doing this mathematically it's not important that you draw it terribly accurately. We really only are going to use our diagram to guide our thinking. A ruler and actual measurements are not needed.

For this vector the right side is called the "tail end" and the left side is called the "tip end". I like to think of the tail end as the starting point and tip end as the ending point.

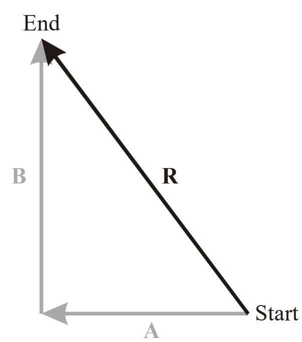
Now let's also draw vector **B**. It is essential that we draw it in the correct way. The "starting end" of B must be at the ending point of **A**. Again this is sometimes called "tip to tail" as the tip of **A** will be the same location as the tail of **B**.



Consider these two vectors to make a single pathway leading from an overall start point (tail of A) to an overall end point (tip of B).



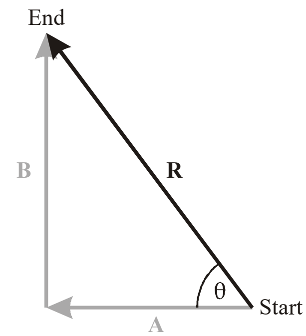
The resultant vector can now be drawn in. It is the new vector that takes the "shortcut" from the same staring point to the same ending point. Note that it points from the start to the end. This means that the resultant does NOT follow the "tip to tail" pattern used for vectors that are being added. Rather, the resultant will actually be "tail to tail" with the first vector, and "tip to tip" with the second vector.



We can now find the magnitude of the resultant by the Pythagorean relationship:

$$R^2 = A^2 + B^2$$
$$R^2 = 3^2 + 4^2$$
$$R^2 = 9 + 16$$
$$R^2 = 25$$
$$R = \sqrt{25}$$
$$R = 5$$

As for the direction, we need to find the angle at the starting end of the resultant. This is the angle θ shown below. Again - the angle that we are interested in is always at the "tail end" of the vector being described.



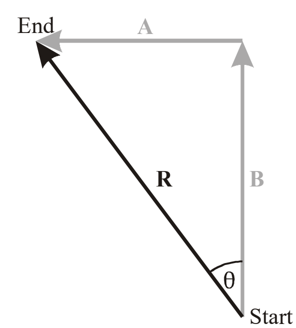
We can now use trig ($\tan^{-1}$) to find the value of this angle.

$$\tan\theta = \frac{opposite}{adjacent}$$
$$\tan\theta = \frac{4}{3}$$
$$\theta = \tan^{-1}\left(\frac{4}{3}\right)$$
$$\theta = 53.1°$$

Thus the final answer to this question is **R** = 5 @ 53.1° north of west

Note: if you get an answer of 0.927 to the above calculation for the angle ... your calculator is in Radian mode! You will need to set it to Degree mode for physics.

When adding vectors, the order in which you add the vectors is actually not important. Here is how the above example would go if we had added the same vectors in the reverse order - i.e. consider vector B to be the "first" vector and A to be the "second" vector.



$$R^2 = B^2 + A^2$$
$$R^2 = 4^2 + 3^2$$
$$R^2 = 16 + 9$$
$$R^2 = 25$$
$$R = \sqrt{25}$$
$$R = 5$$

$$\tan\theta = \frac{opposite}{adjacent}$$
$$\tan\theta = \frac{3}{4}$$
$$\theta = \tan^{-1}\left(\frac{3}{4}\right)$$
$$\theta = 36.87°$$

And so the final answer here is **R** = 5 @ 36.9° west of north

Notice that the two answers (***R*** *= 5 @ 53.1 ° north of west* and ***R*** *= 5 @ 36.9 ° west of north*) don't quite look the same. They seem to agree on the magnitude (5) but disagree on the direction. This is actually not true. They agree with each other perfectly. In fact, this is a very important thing to realize: for vectors that require the use of an angle to describe their direction, there are always two different (but correct) ways to describe their direction.

The two ways of stating such a direction always have the following two properties:

- The two angles will always be complimentary to each other (i.e. they add up to 90°)
- The description of directions will always be the reverse of each other (e.g. "north of west" and "west of north).

This is especially important on a multiple choice question. If you have found the direction of a vector for the answer to a question, but your answer is not one of the listed options, try looking for the other "version" of the direction (i.e. complimentary angle & reverse order words for directions).

Resolving Vectors

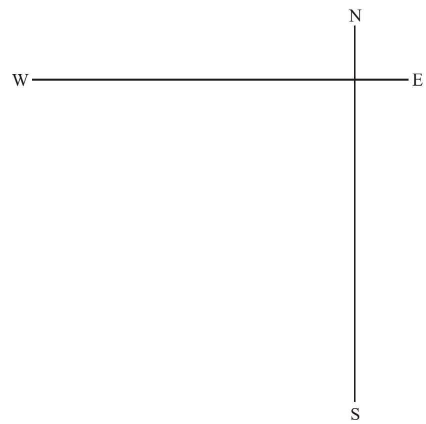
In a way "resolving" a vector is the opposite of adding perpendicular vectors. When you add two perpendicular vectors you are essentially finding the single vector that gets you directly to the "same place" as the two vectors being added (thinking of the vectors as forming a path). Resolving a vector begins with a single vector, and then finds two perpendicular vectors that together get you to the "same place" as the original vector being resolved. These two new vectors are called the **vector components** of the vector that got resolved.

To resolve a vector, just think of it as the hypotenuse of a triangle that you are about to make with two new vectors. These two vectors must have a common start point, and a common end point as the original vector. Then simply find the size of these vectors using trig (one component will be found with sin and the other with cos). The following example should help make sense of this:

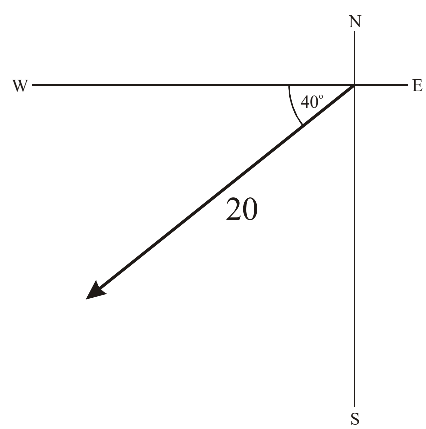
ADDING TWO VECTORS GIVES YOU A SINGLE VECTOR THAT "GETS YOU TO THE SAME PLACE". RESOLVING A VECTOR "BREAKS IT DOWN" INTO TWO "COMPONENT" VECTORS THAT TOGETHER "GET YOU TO THE SAME PLACE".

e.g. *Resolve the vector* ***E*** *= 20 @ 40 ° S of W into its component vectors:*

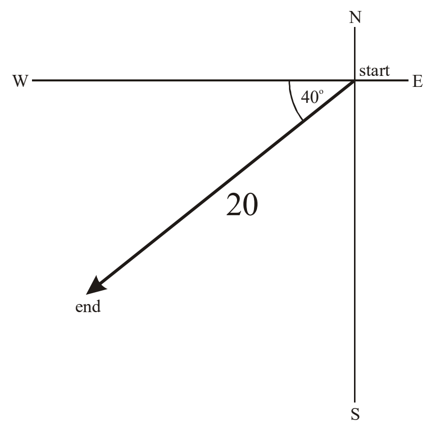
First start by drawing a "coordinate grid" showing N/E/S/W - though it helps to make the quadrant that will contain our vector bigger than the other quadrants. In this case, our vector is in the SW quadrant:



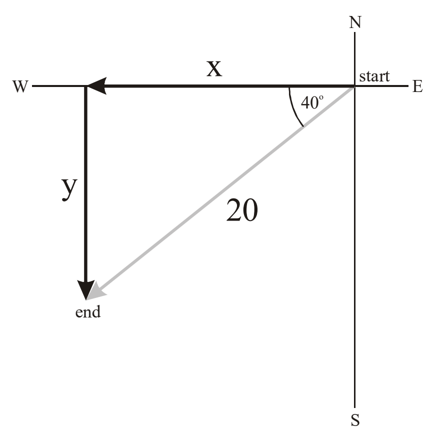
Then draw in the vector, taking care to get the angle in the correct place. In this case, since west is listed last (40° S of <u>W</u>) the 40° angle must "touch" west as shown here:



Again, think of this vector as a "path" with a start and an end.



Now add in two “nice” vectors (vectors that align with the axes of the coordinate grid) that will get you from the same start to the same end. Hint: you should be “building around” the given angle.
Now find the size of each of these component vectors using sine for one of the components and cosine for the other. It is common to refer to them as the “x component” and “y-component” (as seen in the diagram above). Note that depending on how the triangle is drawn up, cos might find the x component OR the y component (with sin finding the other component). You have to think through the trig relationships each time!



$$\sin(40°)=\frac{opposite}{hypotenuse}$$
$$\sin(40°)=\frac{y}{20}$$
$$y=20\sin(40°)$$
$$y=12.856$$

Note that from the diagram, the y component points south, so **y** = 12.9 [S]

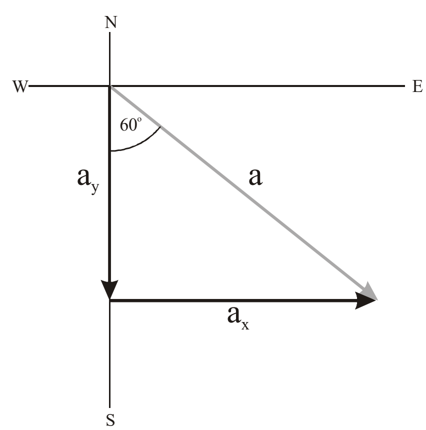
$$\cos(40°)=\frac{adjacent}{hypotenuse}$$
$$\cos(40°)=\frac{x}{20}$$
$$x=20\cos(40°)$$
$$y=15.321$$

Note that from the diagram, the x component points west, so **x** = 15.3 [W]

e.g. *Resolve vector **a** = 225 @ 60 °E of S*

Note that when vectors have a letter "name" (**a** in this case) it is common to label the components with this same label, with x and y subscripts (i.e. we will call the x component "$\mathbf{a_x}$" and the y component "$\mathbf{a_y}$").

Start by drawing in the vector **a** and its components:



Then use trig to find the size of the components:

$$\sin(60°)=\frac{opposite}{hypotenuse}$$
$$\sin(60°)=\frac{a_x}{a}$$
$$a_x=a\sin(60°)$$
$$a_x=225\sin(60°)$$
$$a_x=194.86$$

$\mathbf{a_x}$ = 195 [E]

$$\cos(60°) = \frac{adjacent}{hypotenuse}$$
$$\cos(60°) = \frac{a_y}{a}$$
$$a_y = a\cos(60°)$$
$$a_y = 225\cos(60°)$$
$$a_y = 112.5$$
$$\mathbf{a}_y = 113 \text{ [S]}$$

Case 3: Adding "Ugly" Vectors

OK - so we've covered how to add vectors that are in the same (parallel) or opposite (antiparallel) direction - that's easy and basically amounts to adding the magnitudes and sticking with the same direction (for parallel vectors) or subtracting the magnitudes and sticking with the direction of the larger (for antiparallel vectors). We've also covered how to add perpendicular vectors (which basically amounts to making a right triangle and using trig to find the length and direction of the hypotenuse, which is the resultant (sum) of the perpendicular vectors. And we just covered how to "break a vector down" into its components, which is called "resolving" a vector.

When you need to add vectors that are *not* in one of the *special* cases described above (i.e. they are not parallel, antiparallel or perpendicular), then we have what is called the "*general* case" but I like to call this adding "ugly" vectors. How to do this will be best seen in an example right away, but here's an overview of what we need to do.

First, we are going to resolve each vector into its components. This means we will have two x-components and two y-components. We will then add the two x-components to get a "resultant of the x components" (we'll call this $\mathbf{R}_x$) and we will also (separately) add the two y-components to get a "resultant of the y components" (we'll call this $\mathbf{R}_y$). Note that getting $\mathbf{R}_x$ and $\mathbf{R}_y$ is guaranteed to involve adding parallel or antiparallel vectors, which we are now experts at. Note that $\mathbf{R}_x$ and $\mathbf{R}_y$ are guaranteed to be perpendicular to each other, and wouldn't you know it ... we're pretty good at adding perpendicular vectors too, so we'll do that next. We'll call this "**R**" and note that it is the resultant of the original vectors we were asked to work with.

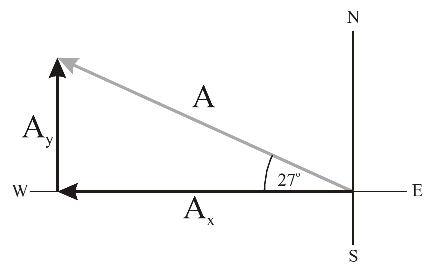
Here it is again, in point form. To add two "ugly" vectors ...

- resolve the first vector into its components
- resolve the second vector into its components
- add the x components from the above to get the "x subtotal" and call it $\mathbf{R}_x$
- add the y components from the above to get the "y subtotal" and call it $\mathbf{R}_y$
- add $\mathbf{R}_x + \mathbf{R}_y$ to get **R** - the "grand total" and answer to your question

If you're still a bit unsure about this, stepping through it with the next example should help.

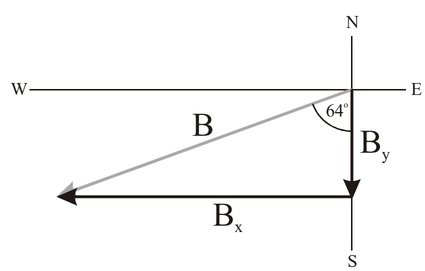
Given $\boldsymbol{A}$ = *13.2 @ 27 °N of W*   *and* $\boldsymbol{B}$ = *17.8 @ 64 °W of S*   *Find* $\boldsymbol{R} = \boldsymbol{A} + \boldsymbol{B}$

• resolve the first vector:



$$A_y = A\sin 27° \qquad A_x = A\cos 27°$$
$$A_y = 13.2\sin 27° \qquad A_x = 13.2\cos 27°$$
$$A_y = 5.9927\ [N] \qquad A_x = 11.761\ [W]$$

• resolve the second vector:



$$B_y = B\cos 64° \qquad B_x = B\sin 64°$$
$$B_y = 17.8\cos 64° \qquad B_x = 17.8\sin 64°$$
$$B_y = 7.803\ [S] \qquad B_x = 15.999\ [W]$$

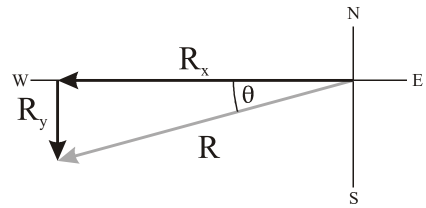
• Add the x components to get $\mathbf{R_x}$

$$R_x = A_x + B_x = 11.761\ [W] + 15.999\ [W]$$
$$R_x = 27.76\ [W]$$

• *Add the y components to get* $\boldsymbol{R_y}$

$$R_y = A_y + B_y = 5.9927\ [N] + 7.803\ [S]$$
$$R_y = 1.8103\ [S]$$

• *Add the "subtotals"* $\boldsymbol{R_x}$ *and* $\boldsymbol{R_y}$ *to get the "grand total"* $\boldsymbol{R}$



$$\tan\theta = \frac{opp}{adj}$$

$$\tan\theta = \frac{1.8103}{27.76}$$

$$\theta = \tan^{-1}\left(\frac{1.8103}{27.76}\right)$$

$$\theta = 3.7311°$$

$$\theta = 3.73°$$

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

$$R = \sqrt{27.76^2 + 1.8103^2}$$

$$R = 27.819$$

$$R = 27.8$$

$\boldsymbol{R}$ = *27.8 @ 3.73 ° S of W*

also correct: **R** = 27.8 @ 86.3° W of S

What the Heck Does this Have to Do with Physics?

Holy crap - I was having so much fun with vectors that I almost forgot this is a physics course!

Actually in all seriousness, it's easy to get hung up on the math of this chapter. And let's be clear: vectors are math - not physics. So why did we just cover so much about vectors? The answer is simple and important: many of the measurements that we study in physics are vector quantities. Consider the motion of an object (details coming beginning in chapter 2). The movement of an object has a magnitude (how fast) and a direction. We actually call this velocity, but we'll formally introduce this in chapter 2. In chapter 4 we'll introduce force, which is also a vector: how hard are you pushing (magnitude) and which way are you pushing (direction)? It goes on and on. Vectors are really important in physics. Get comfortable with them - they're not going away anytime soon.

Chapter 1 Summary

Congratulations! You just made it to the end of chapter 1! Here's a quick reminder of what you should have gotten out of this chapter:

- ☐ You have *memorized* the list of SI units presented at the start of this chapter
- ☐ You have also *memorized* the SI prefixes presented at the start of this chapter
- ☐ You can make *conversion factors* from knowledge of how two units compare to each other
- ☐ You can use the above conversion factors to actually convert units
- ☐ You know what "vectors" and "scalars" are
- ☐ You know that vectors are identified in typing with a **bold** font, and in hand-writing with an arrow symbol (⇀)printed above the letter.
- ☐ You understand the difference between "30° N of E" and "30° E of N" - and can draw vectors correctly based on directions such as these descriptions.
- ☐ You can add vectors that point in the same direction (parallel vectors)
- ☐ You can add vectors that point in opposite directions (antiparallel vectors)
- ☐ You can add vectors that are perpendicular
- ☐ You can resolve a vector into its components
- ☐ You can add vectors that are in none of the above "special" cases (i.e. the general case")

Chapter 1 Problems

Here are just a few problems to get you working right away. This is NOT enough! The answers to these problems appear at the end of this chapter, and are rounded off to 3 figures.

1. What is the SI unit for
   a) mass   b) length   c) time

2. Convert the 90 km/h to m/s

3. Suppose that a Martian dollar is worth $155 Earth Dollars (1M = 155E). A Martian dollar is also worth 0.05 Lunar dollars (1M = 0.05 L), determine the cost (in Earth dollars) of a moon rock that costs 27 Lunar dollars.

4. How many mg are in 25 Mg?

5. Add these 2 vectors: A = 40 @ 30° E of N   B = 65 @ 40°S of W

Answers

1. a) kilogram   b) metre   c) second

2. 25 m/s

3. 83 700 Earth Dollars

4. 25 000 000 000 mg = 2.5×10^{10} mg

5. 30.6 @ 13.5° S of W (or 30.6 @ 76.5° W of S)

Chapter 2 - Motion in a Straight Line

OK, for real: this is a crazy easy chapter in that the actual physics introduced in it is literally as simple as it gets. And yet, in a way it is a very hard chapter as you have to learn how to "do physics" in the general sense in addition to the actual content of this chapter. The nice thing is that once you get past chapter 2 (say by the time you're well on your way in chapter 4) ... you should be able to look back to chapter 2 and wonder how it ever gave you hard time. Trust me - it'll happen, so don't get too down if at first chapter 2 seems hard.

One of the reasons why chapter 2 is initially tough is that among other things, you have to deal with a bunch of new vocabulary. You also have to learn how to work though physics problems, which is not an easy thing to get the hang of (though you will get the hang of it with perseverance and hard work!) By the way - the name of this chapter is a lie. We're not going to limit ourselves to motion in a straight line, but it will be the focus of the chapter nonetheless.

One more comment about this chapter: Due to there being so many ideas being introduced here, this is definitely one of the longer chapters. Do NOT rush through chapter 2! You need to really master the ideas introduced in this chapter. Here's a minor "spoiler" for you: chapter 3 is actually really short. In fact, if you really get good at chapter 2, you can learn chapter 3 very, very quickly, so consider your time spent in chapter 2 to be time very well spent!

How to Solve Problems

In a very short time from now, we are going to encounter our first physics problem. Before we get there, let's learn how to tackle problems in a very generic way. When the problems start to get tricky, students will frequently complain "I don't even know where to begin". Students who say this do not know how to solve problems. You will never make such a complaint in the future because you're about to learn how to work though problems.

A typical physics problem consists of a "wordy" scenario which gives you some information and asks you to determine something based on the physics you have learned. Of course we haven't learned any physics whatsoever at this point, so let's not even try to do a physics problem. Let's try to do a very basic math problem instead. The point of this exercise is not the problem itself ... don't forget that this is actually a lesson on how to solve problems.

When you first encounter a problem, I generally advise that you read it at least twice. The first time you read it, pay no attention at all to the numbers that are given. Instead, try to get a good sense of what is going on in the problem - try to visualize what's happening, and what you're looking for. Try this for the problem below. Every time you come across a number the first time you read it, skip over the numbers. Literally - say the word "whatever" in your head instead of the actual number printed in the problem. Oh - for all problems, if it helps - consider drawing a very simple (non-artistic) diagram to help better understand what's going on. I did not say always draw a diagram - I said *consider* drawing a diagram. Only draw one if helpful.

> READ THROUGH EACH PROBLEM COMPLETELY, PAYING NO ATTENTION TO THE NUMBERS THE FIRST TIME YOU READ IT. TRY TO GET A SENSE OF WHAT IS GOING ON IN THE PROBLEM. DRAW A DIAGRAM IF HELPFUL.

Here is the problem: *A physics student goes into a restaurant for lunch on a sunny Wednesday afternoon and orders a circular pizza with Ham and Pineapple toppings. The pizza costs $20 with taxes and has a 12* *inch diameter. The student eats half of the pizza for lunch and then saves the other half for tomorrow's breakfast. What is the area of the pizza that was purchased?*

Ok - so we've got a person who ordered a pizza, and we want to know the area of the pizza. Did it matter that it was a physics student? No. Was it important that this took place on a "sunny Wednesday afternoon?" No. The cost? Irrelevant. I'm not kidding - a LOT of physics problems are full of crap information and a part of your job is to cut through the crap in order to extract out the important bits. Now that you have a general sense of what the problem is about, you can get to actually solving it. To do this, I like to use an approach which is abbreviated down to the "GUESS" method. The letters of "GUESS' actually stand for important steps you need to take - the idea is not to "take a guess" at solving the problems, but to rather "use the GUESS method". It's actually a fortunate acronym because if you ever find yourself tempted to say "I don't even know where to begin" on a physics problem - the answer actually is "GUESS!"

Here is what the letters each stand for:

<u>G</u> list off the relevant information that has been <u>G</u>iven in the problem. In other words, list off the "<u>G</u>ivens." Convert to SI Units if they are not already in SI Units.

<u>U</u> identify and state the <u>U</u>nknown, which is what the problem asks you to find.

<u>E</u> state the <u>E</u>quation(s) (or formulas) that link the Givens to the Unknown.

<u>SS</u> <u>S</u>ubstitute the values of the Givens into the Equation, and <u>S</u>olve for the value of the Unknown. These two "S" steps may be done in the reverse order if preferred (<u>S</u>olving algebraically and then <u>S</u>ubbing in the givens). Basically these two S's together mean "do the math".

Note that the "GUESS" method is a guide only. It works great for simple problems, but as problems get more difficult, flexibility is often needed! Yet even for really hard problems, the steps in GUESS are usually very helpful in organizing your thinking. Let's see how the GUESS approach helps with the above problem.

> TO SOLVE PROBLEMS, USE THE "GUESS" METHOD TO GUIDE YOU THROUGH THE PROBLEM. LIST OFF THE INFORMATION THAT IS <u>G</u>IVEN, STATE THE <u>U</u>NKNOWN AND <u>E</u>QUATION(S) NEEDED. THEN DO THE MATH BY <u>S</u>UBBING VALUES IN AND <u>S</u>OLVING.

<u>G</u> Now that we have read through the problem and have a sense of what its about, we're going to ignore the details about the day of the week, the cost of the pizza, etc. This problem is really only about the size of the pizza, and we are told its diameter, which really is the only relevant information that we are "Given." So we'll start by recording this bit of information down as a mathematical statement. We'll use the symbol "D" for diameter. Note that we must default to SI units in physics (and we are pretending this is a physics problem.) We are given the diameter in inches, but the SI unit for lengths is actually metres. Fortunately, I happen to know that one inch is about the same as 2.54 centimetres. You don't need to know that by the way (though I think it's generally useful to know!) We also know that the metric prefix "centi" stands for the scientific notation value $\times 10^{-2}$ (good thing we memorized the prefixes from the previous chapter!) We'll use this information to convert the diameter into the SI unit of metres straight away. By the way, I'm going to use "i" for inches, though I have to admit this is not quite standard (fortunately I don't care, especially since it's not SI anyway).

$$D = 12i\,\frac{2.54cm}{1i} = 30.48cm = 30.48\times10^{-2}m = 0.3048m$$

U So as to not lose track of what we're actually looking for in this problem, we are now going to state what the problem has asked us to find. I like to do this by literally printing in a question mark as shown here, in which I am using A for area:

$$A = ?$$

E We now need an Equation that links the given information (diameter) to the unknown (Area). Unfortunately, I don't know of any such equation (or at least I'm going to pretend to not know of any such equation). Here's where a bit of flexibility comes in. I do know that the area of a circle can be found from the radius of the circle ... and I also know that I can find the radius from the diameter. In other words, I can think of *two* equations that together will be useful. I'm going to state them both:

$$A = \pi r^2 \qquad r = \tfrac{1}{2}D$$

By the way - if at any point you were thinking "$2\pi r$" - that's how you find the *circumference* of a circle, which is of no interest to us in this particular problem.

SS In effect, the two S's here mean "do the math". Here it goes:

$$r = \tfrac{1}{2}D = \tfrac{1}{2}(0.3048\text{ m}) = 0.1524\text{ m}$$

$$A = \pi r^2 = \pi(0.1524\text{ m})^2$$

$$A = 0.072966\text{ m}^2$$

$$A = 0.073\text{ m}^2$$

note that I used the "pi" button on my calculator, and also that I rounded off the final answer a bit. Oh - speaking of rounding off ....

Sig Figs

I'm going to assume that you know what Sig Figs are, and how to work with them. If you don't, you will need to learn this for labs. Outside of labs, Sig Figs are not a big deal in this course. In fact, physics generally does not actually care all that much about Sig Figs, but we'll discuss that further in the future. For now, let's just know that we need to know a bit about them.

I have to be honest: I *hate* Sig Figs. I understand them, and I also appreciate their importance when dealing with real-life, actual measurements. The problem is that when we're doing textbook and exam problems in a course like this, we're almost never dealing with real life measurements - and so Sig Figs in such problems are basically a waste of time (again: this does not apply to the labs). As a result, I follow my own (as in - *I made this up* - this is not "official" in any way) simplified set of rules I use for solving "pen and paper" physics problems. Basically, I want to prevent two things. First, I want to avoid "premature rounding off" by losing way too much information. In the above example, it would have been inappropriate to round off the radius of the circle to 0.2 m when I did the conversion (which is why I didn't do that). Secondly, I want to avoid having so many Sig Figs as to be inconvenient (and unnecessary). I could have for example, reported the Area to be calculated as 0.0729658769900396762061561 2418564 m^2, which is what (I'm not kidding) my calculator *actually reported* (and yes - different calculators will show more or fewer figures in a calculation like this).

So here is my personal, simplified set of rules: I like to round off "partial answers" (numbers that I need to record, but are not the "final answer" to the problem) to five significant digits. I then report the final answer to three significant digits. One last thing: I never "force" there to be more significant digits than would be "natural". Technically my above answer for the area (0.073 m^2) only has two significant digits, but the third one would be a zero: 0.0730 m^2). I just don't bother with this "unnatural" way of writing numbers down.

Is it "OK" to use my simplified rules? Definitely NOT in labs. But actually, yes, it is OK to use them in the problems that come up outside of the labs. It is even OK to use these rules on the AP Physics exams. Oh - but NOT in Chemistry! Chemistry people appear to LOVE Sig Figs. If you are also in a Chemistry course (especially AP Chemistry), you probably cannot use my simplified approach there!

I USE A SIMPLIFIED APPROACH TO SIG FIGS: "PARTIAL ANSWERS" TO 5 SIG FIGS; FINAL ANSWERS TO 3 SIG FIGS; BUT DON'T "FORCE IT"

General Vocabulary

Before getting into a few specific examples of words you need to know the meanings of, I'd like to say that it is sometimes the case that words have a very specific meaning in physics which may or may not be the same as the way that same word is used in ordinary conversation. The three words introduced below (Mechanics, Kinematics and Dynamics) are not good examples of this as they are words that are pretty much never used in ordinary conversation (let's not even talk about people who fix cars as that is hopefully very clearly a completely different use of the word "mechanics").

I'm really thinking about words like "weight" and "work" and "energy" ... these are all words that do have an "every day meaning" that is quite different from the precise way they are used in physics. I'll remind you of this when we actually introduce those words in future chapters, but do consider that words often have a casual meaning that is different from their scientific meaning. Here are some words that are worth knowing the meaning of. We will use these words often in the future.

Mechanics Avoiding an overly formal definition, mechanics is basically the study of motion and is itself broken into two parts: Kinematics and Dynamics. This course starts off with a fairly large unit of mechanics. Chapters 2 to 11 are all mechanics (chapters 0 and 1 were introductory with no actual physics).

Kinematics Kinematics is the study of movement with no regard for the underlying principles or causes of the motion. If you're asking questions like "how far did it go", "how fast was it going" and "how long did it take to get there" then you're doing kinematics. Kinematics is the focus of both chapter 2 and chapter 3, though it does show up in nearly all subsequent chapters as well.

Dynamics Dynamics is the part of mechanics that is avoided by kinematics, namely, dynamics addresses the causes and underlying principles of motion. Dynamics is introduced in chapter 4 with additional elements being introduced in subsequent chapters.

With these terms in place, we can now say that Chapter 2 really is an "introduction to Kinematics". Chapter 2 does occasionally go beyond straight line motion, but in a pretty simplistic way. By the way - chapter 3 literally is "Kinematics in two Dimensions".

Distance and Displacement

Distance and displacement both measure "how far" an object moves and yet they do NOT mean the same thing. Distance is a measure of the *length of the path taken by an object*, while displacement is a measure of *how far an object has moved from where it began ... and also in which direction it moved*. Note that distance has only one part: a "magnitude" (how long the path taken is) while displacement has two parts: a magnitude (how far away it ended up) and also the direction. This means that distance is a scalar while displacement is a vector. This is why the symbol for distance is a "d" while the symbol for displacement is "**d**" (notice that the vector displacement is in bold, though it can also be printed as $\vec{d}$.

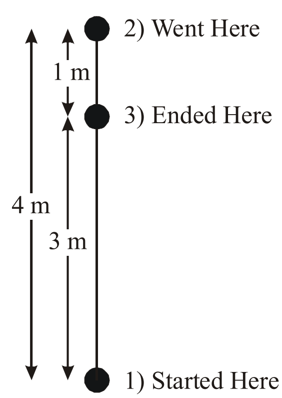
At this point a lot of people make a critical mistake: some people think that displacement is simply the distance an object moves ... plus the direction. This is NOT the case. Let's have a closer look at the definitions, and apply them to a couple of examples.

> DISTANCE IS THE LENGTH OF THE PATH TAKEN BY A MOVING OBJECT. DISTANCE IS A SCALAR, SYMBOLIZED AS "d" - THE SI UNIT FOR DISTANCE IS THE METRE

Consider an object that moves 4 metres north. It then stops, turns around and then moves 1 metre to the south. This object moved a distance of 5 metres. This is because the object moved through a path 5 metres long. It doesn't matter that the path in this particular case had a "fold" in it. It was a 5 metre long path nonetheless.

> DISPLACEMENT IS A MEASURE OF HOW FAR (AND IN WHICH DIRECTION) AN OBJECT ENDED UP COMPARED TO WHERE IT BEGAN. DISPLACEMENT IS A VECTOR, SYMBOLIZED AS "**d**" - THE SI UNIT FOR DISPLACEMENT IS THE METRE

By comparison, displacement completely ignores the "path taken". It only looks at where the object was when it began, and where was when it ended. Everything in-between those moments is ignored. Literally:



how far away did it end up from where it began, and in which direction? For the object just considered, it should be clear that it ended up 3 metres north of where it began, and that is indeed its displacement. Consider a diagram:

The movement consisted of two parts. The length of the first path taken was 4 m, and then the length of the second path taken was another 1 m. The symbol for distance is the letter "d". Using this we can say this: $d_1 = 4$ m, $d_2 = 1$ m. The total distance is simply $d_1 + d_2$:

$$d_{total} = d_1 + d_2 = 4 \text{ m} + 1 \text{ m} = 5 \text{ m}$$

Similarly, the symbol for displacement is **d** (notice the boldface, which makes it different from the d for distance). Using this we can say this: $\mathbf{d}_1$ = 4 m [north],
$\mathbf{d}_2$ = 1 m [south]. The total displacement is simply $\mathbf{d}_1 + \mathbf{d}_2$ (adding vectors this time!)

$$\mathbf{d}_{total} = \mathbf{d}_1 + \mathbf{d}_2 = 4 \text{ m [north]} + 1 \text{ m [south]} = 3 \text{ m [north]}.$$

In other words, we can say both of these things for the object under investigation:

- It moved a distance of 5 metres
- It moved a displacement of 3 metres to the north

The cool thing is that both of these correctly address "how far" the object moved, and yet they do so in subtly different ways. They are both important in their own way. Notice that the total distance was found using (ordinary) scalar addition, while the total displacement was found using vector addition (specifically antiparallel vectors as introduced in the previous chapter).

I want to stress that distance and displacement are both important, but in some situations we might find one or the other to be more useful. Let's look at two examples to make this clear:

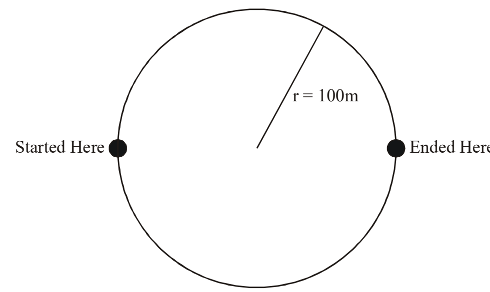
- Suppose you are considering purchasing a used car. What would be more important to you: the *distance* the car has moved since it was new, or its *displacement?* Answer: the distance really tells you how much "driving" the car has been subjected to, and so is a good indication of how much "usage" it has had. In fact - the odometer (the readout on the dash that indicates how many kilometres the car has on it) is literally a readout of the "length of the path taken" by the car. Imagine that you are shopping for this used car at the same car dealer that sold it as a new car a few years ago. In a way, this used car (that may have been driven for thousands of kilometres) would have a *displacement* of zero (!) since in this case, the car has "ended up" at the same place it started. That's kind of neat, but of no real use in assessing how "used" the car actually is.

- Now consider the motion of a golf ball that has been hit from a tee: it arcs up high into the air before falling back down to the ground. What is more important to the golfer: the distance the ball moves, or the displacement that it moves? Realize that the distance would literally be the length of the path taken by the ball. Although I'm not suggesting you could actually do it, imagine taking a very long tape measure and using it to "trace out" the curved path that the ball actually moved through the air. This length would be the distance the ball moved. Notice that even if the ball were to have gone straight up (really high!) and then straight down to land right back on the tee, the distance would still have been considerable. Again - this might all be interesting, but generally a golfer is much more concerned about "how far away the ball ends up from where it started - and in which direction!" This is of course the ball's *displacement*, and it would be much more important than the ball's distance in this scenario.

So how come people confuse distance and displacement so often? My guess is because *sometimes* they do appear to be very similar. What if an object moves 4 metres north, and then moved an additional 1 metre north? Applying the same line of reasoning as above, we would find that this object moved a total distance of 5 m, and also that it moved a displacement of 5 m [north]. In this particular case distance and displacement *seem* be the same - except that displacement includes a direction. Of course, this will only be true for objects that only ever move in exactly one direction ... which won't always be the case.

> DISTANCE AND DISPLACEMENT ARE QUITE DIFFERENT FROM EACH OTHER. DISTANCE PAYS ATTENTION TO THE ACTUAL PATH TAKEN (ITS LENGTH) WHILE DISPLACEMENT IGNORES THE PATH TAKEN (BEING ONLY ABOUT HOW FAR AWAY - AND IN WHICH DIRECTION - AN OBJECT ENDED UP FROM WHERE IT BEGAN).

e.g. *A girl begins at the western-most point of a circular track that has a radius of 100 m. She then walks halfway around the track. Find (a) the distance that she walked; (b) her displacement.*



Let's draw a diagram. Note that we don't actually know which way the girl walked (we don't know if she initially moved north or south) but it turns out we don't really need to know this.

(a) Distance is the "length of the path taken". From the diagram it should be clear that the path taken is half of the circle's circumference. Let's use our "GUESS" approach to guide us through solving this problem. Note that I don't actually label the steps like I did when introducing the method, but you should be able to spot each of the steps as they happen!

$r = 100$ m
$d = ?$
$d = \frac{1}{2} C \qquad C = 2\pi r$
$C = 2\pi(100 \text{ m}) = 628.32$ m
$d = \frac{1}{2} C = 0.5\ (628.32 \text{ m}) = 314$ m

By the way - a friendly reminder: notice how I have used my simplified approach to Sig Figs. I recorded the circumference (a "partial answer") to 5 figures, and the final answer to 3 figures.

(b) Displacement ignores the path taken and only focuses on "how far she ended up ... and in which direction". From the diagram it should be clear that she has ended up on the other side of the circle, which is 200 m away (the diameter of the circle). She has also ended up directly east of where she began, so the answer to this question (with no work needed to be shown) is **d** = 200 m [east].

A Comment about your Textbook

I'm assuming that you are using a "real textbook" in addition to these notes (which I am purposely not thinking of as a "real textbook"). It is my opinion that most real physics textbooks are terrific resources for somebody who already knows physics, and just needs to look up a detail that they've forgotten, but they are (again in my opinion only) generally not very good at actually teaching physics to somebody who doesn't yet understand it. Also - I generally do NOT like the choice of letters used for measurements in most textbooks. You should know that the letter symbols for quantities in physics are not entirely standardized. It is not unusual for different physics textbooks to use different symbols. It's not like the symbols for elements in chemistry. There's just no way a chemistry book (or chemistry teacher) would say something like "I don't like using 'H' as the symbol for hydrogen ... I think I'm going to use 'Hy' instead." Nope - the symbols for elements are just way too standardized to get away with something like that. This is NOT the case with physics symbols; we actually do have some flexibility in our choice of letter symbols. As seen above, I like to use "d" for distance (and "**d**" for displacement). Some books actually use these same symbols. Some books use other letters. For example, it is not uncommon to see "$\Delta\mathbf{x}$" used for displacement.

I'm generally not going to make an effort to use the same symbols as any particular textbook. Fortunately most will turn out to be the same anyway, but in those cases that I use a different symbol, I'm going to strongly encourage you to use my symbols - not those of your textbook. In most cases, this is not because I merely have a "preference" that I'm trying to impose on you. Rather it's because I genuinely believe there is a benefit to using my symbols over those of the text. Generally my symbols avoid long-term confusion (though occasionally at the expense of causing a short term confusion). Nonetheless - I'd like to reassure you that I've put a lot of thought into my choices of symbols, and students who give them a try generally find that they are a great way to do physics.

YOU DON'T NEED TO USE THE SAME SYMBOLS USED BY YOUR TEXTBOOK. THE SYMBOLS USED IN THIS BOOK WILL BE THE SAME AS YOUR TEXTBOOK FOR MOST BUT NOT ALL THINGS. THERE IS A REAL LONG-TERM BENEFIT IN USING THE SYMBOLS USED IN THIS BOOK INSTEAD OF YOUR TEXTBOOK!

Time

I'm not even going to try to talk about what time "really" is. In a way, we all "know" what time is, and yet the more you think about it, the more you find that it is way more complicated than you might at first have thought. Instead, we'll just sneak by with a "casual" understanding of time. In the context of kinematics, we use time to measure "for how long" an object that we are analysing the motion of has moved.

In physics problems, we usually have a definite moment that we "start caring" about things, and another definite moment that we "stop caring" about things. In this context, "time" is a measure of how long it took between these moments. Sometimes we might be interested in the "whole motion" of an object. For example, a ball may have been at rest on the ground. It then got kicked, rolled for a while, and eventually stopped. In this situation (if we choose to) we can talk about the entire amount of time that it was moving.

At other times, we may only be interested in a portion of an object's motion. In these cases, we use "time" for the duration of the movement that want to pay attention to. The ball just mentioned may have been rolling along for ten seconds, but maybe we are interested in only the first one second of its motion for some reason. In this case, the "time" of the motion being considered would be only 1 second, with the remaining 9 seconds it was moving for being ignored.

The SI ("official") unit of time in physics is the second, abbreviated "s" (not "sec"). The symbol I use for time is "t" ... notice that this is a lower case letter. Remember: do NOT change any of the symbols on me! Some students make the mistake of using an upper-case "T" here thinking that it's no big deal ... but it actually is! This is not me being picky by the way ... in chapter 5 we'll start using an upper-case "T" for something else, so avoid future grief by getting the symbols correct right from the start.

You can think of "time" here as meaning "what a clock says," though we will usually think of a stopwatch kind of clock, and not a "time of day" clock. We are often interested in not merely a clock reading, but an actual "duration of time" which we symbolize as "Δt". I'm going to talk about that little triangle later in the chapter, but I will say this: for time (but only for time!) the little triangle is often ignored, especially since some people define "t" to mean "duration of time". Again - we're not necessarily using the same symbols as the textbook, so how about if I just say that I will be using "t" for time in general, and Δt for duration.

TIME IS SYMBOLIZED WITH A LOWERCASE "t" AND HAS THE SI UNIT OF THE SECOND (s)

A "DURATION OF TIME" IS SYMBOLIZED AS "Δt" AND ALSO HAS THE SI UNIT OF SECONDS (s)

Quick tip: a hand-printed letter "t" can look a lot like a "plus sign" (+). Make an effort to make your letter t's look distinct, at least inside of mathematical equations. I personally go out of my way (actually it's a habit I don't even have to think about anymore) to have my printed letter t's contain the little "tail" on the bottom, just like how it appears in typing in most fonts (including this one). It might sound like a silly little thing, but I have actually seen many students math go wrong due to a "t" for time morphing into a "+" for addition in the middle of their work.

Speed and Velocity

Just like how "distance" and "displacement" both address "how far" an object moves ... "speed" and "velocity" both address "how fast" an object moves. The difference between speed and velocity is a little trickier though, and in many situations, they are going to seem as if they are very nearly the same, which of course is not generally the case.

First off, speed is a scalar and is symbolized as "v" while velocity is a vector (and so it must have a direction) and is symbolized as "**v**". Again - notice that the vector (velocity in this case) has a symbol showing up in bold, though it would typically be hand-written as $\vec{v}$. Oh - thinking ahead a ways ... in the electricity unit of Physics 2, we will be using an upper-case "V" for an electrical measurement called "potential". It will actually be somewhat common for us at that point to have equations that contain both "speeds" (v) and "potentials" (V). Having both upper-case V's and lowercase v's in the same equation can get tricky, especially if your v's and V's look similar. To avoid this, I strongly recommend you start making your lowercase v's look distinct. I personally put a little "tail" on the end of my lowercase v's, to give it kind of an italicized look. Something like this: *v*. My hand-printed "italicized" v is then very distinct from my hand-printed upper-case V, which basically consists of two straight lines. Sounds stupid and picky I know ... but it really, really makes a difference. Again - I have seen way too many students go awry as a result of their confusing their own letters.

Both speed and velocity have the same SI units: m/s. Note that while not SI, km/h are sometimes used. You should be able to "properly" convert between these units, but there is a handy shortcut that is worth knowing:

TO CONVERT km/h TO m/s, DIVIDE BY 3.6; TO CONVERT FROM m/s TO km/h MULTIPLY BY 3.6

The reason that the distinction between speed and velocity is "tricky" is that we can talk about how fast an object is moving *at one particular moment* (call this an "instantaneous" measurement) **OR** we can talk about how fast an object moved *on average throughout a certain duration of motion* (call this an "average" measurement).

Here's how it works: *instantaneous* values of speed and velocity will always be the exact same size (magnitude) ... but velocity must include a direction. Let's say that while driving in your car, you glance at the speedometer at exactly twelve noon. At that moment, your speedometer indicates you are moving at 90 km/h (which we can divide by 3.6 to find is equal to 25 m/s), and you happen to know that you are moving east. According to this information ....

- at twelve noon, your *instantaneous speed* was 25 m/s, which can be symbolized as v = 25 m/s
- at twelve noon, your *instantaneous velocity* was 25 m/s to the east, which can be symbolized as **v** = 25 m/s [east]

Again - notice that from the above, it looks like velocity merely adds the information about direction, which will actually be true for all *instantaneous* values for speed and velocity: when the motion of an object at a particular moment in time is being considered.

WARNING: The following is going to be confusing! Stick with it ... it will all make sense, but probably not until *after* you have read it all, including the examples. In fact, after you read the examples, you should come back to this point and read it again!

Sometimes we are more interested in the *average* motion of an object over a duration of time, and this is when it gets a bit more tricky. To find the average speed (or average velocity) you need to consider *how far* the object moved, and *how long* it took to move that far. BUT as we just saw ... there are two different ways to measure "how far" an object moves.

So here's the deal: *average speed* makes reference to the *distance* that the object moved while *average velocity* makes reference to the *displacement* that the object moved. This brings us to our very first "formula" in physics, which comes in two "versions" ... one is a scalar version with speed and distance; the other version has the vectors displacement and velocity in it. By the way: placing a "bar" on top of a symbol signifies "average" so $\overline{v}$ means "average speed" while $\overline{\vec{v}}$ means "average velocity". Note that I'm going to use the vector arrow symbols (instead of bold) here to hopefully be extra clear about these two versions.

$$\overline{v} = \frac{d}{\Delta t}$$ (average speed equals distance divided by duration of time for this motion)

$$\overline{\vec{v}} = \frac{\vec{d}}{\Delta t}$$ (average velocity equals displacement divided by duration of time for this motion)

Note in the above that the distance, displacement and durations of time all refer to the *total* amounts for the motion being considered. Also, if an object moves with a *constant* speed (or constant velocity), then it will actually only have one single value for speed (or velocity), and so it would be unnecessary to refer to the "average". When an object moves in this unchanging way, we sometimes call it "uniform motion".

Uniform motion is when an object moves with constant speed (or velocity). In such cases, the actual value of the speed (or velocity) can be found as $v = \frac{d}{\Delta t}$ or $\vec{v} = \frac{\vec{d}}{\Delta t}$

In summary, the formula " $v = \frac{d}{\Delta t}$ " can be used in four different ways:

1. For an object that moves with a constant speed, the "v" is that actual speed, the "d" is the distance moved during an amount of time "Δt".
2. For an object that moves with a varying speed, the "v" is actually $\bar{v}$ (average speed), the "d" is the distance moved, and the "Δt" is the time taken to move that distance.
3. For an object that moves with a constant velocity, the "v" is that velocity ($\vec{v}$), the "d" is the displacement ($\vec{d}$) moved, and the "Δt" is the time taken to move that displacement.
4. For an object that moves with a varying velocity, the "v" is actually $\bar{\vec{v}}$ (average velocity), the "d" is the displacement ($\vec{d}$) moved, and the "Δt" is the time taken to move that displacement.

Trust me - this sounds way more confusing than it actually is. Here are a bunch of examples to help clear it all up:

e.g. *An object moves 20 metres in 10 seconds. What was its speed?*

Answer: "Trick Question" ... all we know is that moved a certain distance (20 metres) in a certain time (10 seconds). Asking for "its speed" implies that it only had one value for speed, but we don't know if that was the case or not. *Maybe* it zipped quickly through the first 15 metres, then moved slowly for the last 5 metres, taking 10 seconds in all. I have no idea if it even had "a" (singular) speed.

e.g. *An object moves 20 metres in 10 seconds. What was its average speed?*

Answer: I still don't know precisely how it moved in this situation, but I don't need to know this in order to describe its *average* speed. Average speed can be calculated according to the equation:

$$\bar{v} = \frac{d}{\Delta t} = \frac{20m}{10s} = 2m/s$$

e.g. *An object moves 20 metres in 10 seconds. What was its average velocity?*

Answer: I don't have enough information to answer this. Velocity (including average velocity) is a vector, and so properly it needs a direction, but I don't know which way the thing moved. Assuming that it moved in a straight line, I can tell you that its displacement will also be 20 metres in size. This means that its average velocity would have a magnitude of 2 m/s, but I would really need to know the direction in order to fully answer this question.

e.g. *An object moved 30 m to the west in 5 seconds, and maintained a uniform motion throughout the whole 5 seconds. What was its speed?*

Answer: Since it had a uniform speed, I can tell you the actual value of the speed: $\overline{v} = \frac{d}{\Delta t} = \frac{30m}{5s} = 6m/s$

e.g. *An object moves 30 m to the west in 5 seconds, and maintains a uniform motion throughout the whole 5 seconds. What was its average speed?*

Answer: Since it had a uniform speed, the average speed will be the same as its actual speed: 6 m/s.

e.g. *An object moves 30 m to the west in 5 seconds, and maintains a uniform motion throughout the whole 5 seconds. What was its average velocity?*

Answer: Its average velocity can be found from its displacement and time: $\overline{\vec{v}} = \frac{\vec{d}}{\Delta t} = \frac{30m[W]}{5s} = 6m/s[W]$

e.g. *An object moves 30 m to the west in 5 seconds, and maintains a uniform motion throughout the whole 5 seconds. What was its velocity?*

Answer: Since it moved with uniform motion, its velocity and average velocity are the same: **6 m/s [W]**

OK - now that we've made it through all that, I have to let you in on a little secret: Textbook and exam problems are often sloppy when it comes down to these ideas. You may, for example, get asked a question just like e.g. 1 above, and the "expected" answer will actually be 2 m/s. This can actually be a bit frustrating at first as you may be trying to be very careful about the terminology and the "actual physics" only to be let down by how problems themselves seem to often not care about these details.

All is not lost though ... we just need to be clear about something that we are now going to introduce as some simplifying principles:

Simplifying Principles

Unless you have good reason to do otherwise (such as information explicitly stated in a problem), we generally assume the following things about motion:

- we assume that all motion is "uniform" unless we have good reason to believe otherwise.
- Although we may not know the "actual" direction of motion, in the context of a problem, we can usually fake it and pretend to know the direction. This is often done by simply taking the direction of motion as being "positive".

Again - textbook and exam problems often require you to use the above simplifying principles. Using these principles, let's have a look at examples 1 and 3 seen above again. This is the way you will actually be expected to answer them!

e.g. An object moves 20 metres in 10 seconds. What was its speed?

Answer: Assuming that it moved with a constant speed (which is the expected thing to do), this object moved 20 metres in 10 seconds, so its speed can be found: $v = \frac{d}{t} = \frac{20m}{\Delta 10s} = 2m/s$

e.g. An object moves 20 metres in 10 seconds. What was its average velocity?

Answer: Assuming that it moved with a constant velocity (which is the expected thing to do), speed and velocity have the same value, but velocity adds direction to the mix. I already found its speed above, so it's velocity is 2 m/s [forwards] or more simply +2 m/s.

If you understood all this on your first read through - congratulations! If you're still a bit confused, maybe you should go back to the to the "Warning" you received a couple of pages back, and read through that again. It's actually not that bad, and honestly: by the time you do a handful of textbook style problems, it gets even more clear, so don't worry if you're still a bit fuzzy on this for now.

Compound Uniform Motion

One interesting scenario you will almost certainly come across is that of an object that moves with a uniform motion for a while, but it then very dramatically changes to a different velocity, which is then maintained for a while longer. In these cases, the transition from one motion to the other is typically treated as being so sudden as to be well approximated as being instantaneous (we pretend that it took no time at all for the change to happen). Here is an example of what I mean:

e.g. A car moves at a constant speed of 10 m/s for 2 minutes. It then suddenly changes to a new speed of 20 m/s which it then maintains for an additional 3 minutes. For the entire motion described, find the car's average speed.

A lot of people would read the above problem and immediately come to the answer that the average speed was "obviously" 15 m/s. Not so! In fact, this is worth putting in a box:

DO NOT FIND AVERAGE SPEEDS BY "ADDING THE SPEEDS AND THEN DIVIDING BY 2"

The answer to this example is actually not 15 m/s. The problem is that the in this case, the car spent *more time* at the greater speed of 20 m/s, and *less time* at the lower speed of 10 m/s. The "average speed" is therefore going to be closer to 20 m/s than it is to 10 m/s. 15 is indeed the average value of 10 and 20, but it is NOT the average speed of this car. To find the average speed, simply use the equation we have already established.

Notice also that we can find how far the car moved in each of the two distinct parts of this motion. Let's solve this problem using our "GUESS" method. I will use subscripts "1" and "2" for the two distinct "parts" of the motion that occurred:

v_1 = 10 m/s
Δt_1 = 2 min = 120 s
v_2 = 20 m/s
Δt_2 = 3 min = 180 s

$\bar{v}$ = ?
v = d/Δt

$v_1 = d_1 / \Delta t_1 \rightarrow d_1 = (v_1)(\Delta t_1) = 10(120) = 1200$ m

$v_2 = d_2 / \Delta t_2 \rightarrow d_2 = (v_2)(\Delta t_2) = 20(180) = 3600$ m

$$\bar{v} = \frac{d}{\Delta t} = \frac{d_1 + d_2}{\Delta t_1 + \Delta t_2} = \frac{1200 + 3600}{120 + 180} = 16\,m/s$$

A Quick Comment on Units

One of the awesome things about SI units is that if you use only SI units within your calculations, you are guaranteed to get an answer that is also in SI units. This guarantee let's me get away with being a bit lazy. Technically, I should have put my units right into the calculations above. Look at the line in which I determined the distance moved in the first part of the motion. Look how I wrote "10(120) = 1200 m". What I really *should* have put is 10m/s(120s) = 1200 m. The units *should* have been used inside the calculation, and when they are, notice how the unit of seconds actually cancels out, naturally leaving the answer in metres.

While it is indeed mathematically incorrect to do it the way I did, I honestly don't care. I will defend my incorrectness as my having that much faith in the SI system. Remember: if you are using only SI units, your answer will always come out in SI units. Feel free to be lazy like me. Simply put, I always make sure I use SI units in my calculations, and as a result, I know my end answer will always have correct SI units ... so I don't bother putting my units into the calculations.

For the record, there are a lot of really smart people (whom I respect tremendously) who strongly disagree with me on this point. Some people feel passionately that you should always put units inside of every calculation (etc.). That actually is really smart, and I get it. I just can't bring myself to do it. I welcome you to do so if you like, but I won't.

While I do indeed love SI units (this is just one reason that they are so awesome), it is the case that for uniform motion, we do quite often come across problems that use kilometres instead of metres, hours instead of seconds, and km/h instead of m/s. As long as the motion is NOT "accelerated" (see below), you can actually go ahead and use all 3 of these units instead of the SI units, and it will work out fine. Just don't mix and match! You have to use km AND h AND km/h (or all SI units). By the way - NEVER use km, h or km/h for any physics that goes beyond the simple v=d/Δt. It is not an "option" (or at least not an option I will advocate for) ... I strongly recommend that you use SI units for pretty much all of the physics we will see. "v=d/Δt" is a rare exception to this policy in that you can use the "alternate" set of units as described above.

Accelerated Motion

Uniform motion is pretty simple. If an object maintains a constant velocity, then that velocity can be found according to the equation $\vec{v} = \frac{\vec{d}}{\Delta t}$ and if an object has a varying velocity, you can still find the *average* velocity according to the equation $\overline{\vec{v}} = \frac{\vec{d}}{\Delta t}$. This section is all about "varying velocities" ... which we call acceleration.

Acceleration is actually one of those words that I talked about earlier in this chapter. Acceleration has one meaning in ordinary (non-physics) usage; to most people "accelerate" means "speed up". You really need to know that our usage of this word is quite different than this. In physics, we use the word accelerate for any time that an object's velocity is changing. This means that an object that is speeding up is indeed "accelerating" BUT ... in physics, we would say that an object that is slowing down is also accelerating(!)

Most people would much rather use the word "decelerate" for an object that is slowing down, but not us. Nope. In fact, I'm going to go so far as to say that the word "decelerate" is a word that I will go out of my way to avoid using. By the way - it gets even worse: in physics it is possible for an object to be accelerating, even if it is moving at a constant speed(!!) I promise that it actually makes sense, but you have to be open minded. By the way - physicists tend to be rather smart. The very least you can do is hear them out ... it turns out that there are incredibly good reasons to use the word "accelerate" the way we do. By the way - for what it's worth - I did not just compliment myself. I am not a physicist (I am a physics teacher), so I didn't just call myself smart. It turns out that I happen to be smart (not to mention witty, handsome, charming and above everything else: modest) ... but I'd never stoop so low as to compliment myself. I prefer to leave that to my legions of fans.

In physics, acceleration is a measure of how quickly an object's velocity is changing. If an object has a constant (unchanging) velocity, then it is not accelerating. If its velocity is changing, then it is accelerating. The more "dramatically" that its velocity is changing ... the greater its acceleration is. Let's consider an example. In this example, we will deal with direction in the "simple" way that we often choose to. We will consider "forwards" to be a direction that we will regard as "positive".

Suppose a car is stopped (velocity zero) at a traffic light that is presently red. At the moment that the light turns green the car takes off. Suppose that a passenger seat starts a stopwatch at the same moment that the light turned green, and that he records the value on the speedometer every second. The values of the stopwatch readings are genuinely values of time (t ... not Δt, which stands for "duration of time") and the car's velocity (forwards being treated as the positive direction) are summarized in the chart below:

Stop Watch Reading (t)	Car's velocity (**v**)
0	0
1 s	10 km/h
2 s	20 km/h
3 s	30 km/h
4 s	40 km/h
5 s	50 km/h

From the above values, it is pretty clear that the car was speeding up (and so it's velocity was indeed changing). In describing "how dramatically" the velocity changed, we can say that the car's velocity increased by 10 km/h *per second*. This can actually be written as 10 km/h /s.

Suppose that the above is repeated, but this time a faster car is used. The results of this run are recorded below:

t	**v**
0	0
1 s	20 km/h
2 s	40 km/h
3 s	60 km/h
4 s	80 km/h
5 s	100 km/h

Clearly this car's velocity changed even more dramatically. Its velocity changed at a rate of 20 km/h /s.

The values 10 km/h /s for the first car, and 20 km/h /s for the second car are actually indications of the accelerations of the cars. The only "problem" is that the units are not SI units. We could go about converting the units into SI units, but let's instead imagine a third car that happens to have a speedometer already marked off in m/s (I've never seen such a car speedometer, but it's not hard to imagine at all).

Suppose this third car moved according to this data, again recorded in the same way:

t	v
0	0
1 s	5 m/s
2 s	10 m/s
3 s	15 m/s
4 s	20 m/s
5 s	25 m/s

Hopefully it is clear that this car gained 5 m/s of velocity each and every second, and so its acceleration can be reported as “5 metres per second, *per second*”. If you say that too quickly, it sounds really weird because you’d actually be saying “per second” twice. But this would be correct, with each “per second” having a subtly different meaning. You see, the first “per second” really is part of the velocity unit in “m/s” while the next “per second” is really about the change that’s occurring. It actually makes more sense if you put a bit of a pause in between them to make this clear: The car’s acceleration is 5 metres per second <*pause*> per second.

Mathematically, we can record this acceleration as 5 m/s /s, but this too looks weird. We usually don’t like to have the same unit (or variable for that matter) appear in two different places in the same measurement ... we usually prefer to “simplify” it, so let’s go ahead and do that. The “slashes” (/) really mean divide, so this can be written like this:

$$m / s / s = m \div s \div s$$

And this might be easier to think about if we make each part look more like a fraction, so let’s do that:

$$m \div s \div s = \frac{m}{1} \div \frac{s}{1} \div \frac{s}{1}$$

Dividing fractions can be achieved by “inverting and multiplying” so the above can be rewritten:

$$\frac{m}{1} \div \frac{s}{1} \div \frac{s}{1} = \frac{m}{1} \times \frac{1}{s} \times \frac{1}{s}$$

Which of course can be simplified by multiplying all of the numerators together (m×1×1) to give the overall numerator (m) and also multiplying all of the denominators together (1×s×s) to give the overall denominator (s^2). This means that

$$\frac{m}{1} \times \frac{1}{s} \times \frac{1}{s} = \frac{m}{s^2} = m / s^2$$

With “m/s^2” being a nicely simplified version of what we started with: the SI Unit for acceleration. The lesson to be learned here is that while “m/s^2” might look a little strange (it’s hard to wrap your head around the s^2 part) ... it really means nothing more than metres per second <*pause*> per second. I find that pause to be really important!

ACCELERATION IS A MEASURE OF HOW QUICKLY AN OBJECT’S VELOCITY IS CHANGING. IT IS SYMBOLIZED AS “a” IN EQUATIONS AND HAS THE SI UNITS OF m/s^2.

Acceleration of an Object Slowing Down

I mentioned above that even an object that is slowing down is considered to be “accelerating” in physics (and the word “decelerate” is to be avoided). Let’s have a look at how this works. Let’s do the stopwatch in a car again, but this time let’s consider a car that is already moving, but in the act of braking to a stop. We will again consider forwards to be the positive direction. Suppose that the following data are recorded:

t	**v**
0	20 m/s
1 s	16 m/s
2 s	12 m/s
3 s	8 m/s
4 s	4 m/s
5 s	0 m/s

Remember: acceleration describes the change that is occurring to the velocity, so let’s just ask this question: how is the velocity of this car changing? One good answer would be to say that “the car’s velocity is having 4 m/s *subtracted* each second.” It might be a bit less natural, but another way of saying this is to say that the car is “gaining -4 m/s of velocity each second” which is to say that its velocity is changing at a rate of -4 m/s^2. Indeed, we would say that this car has an acceleration of -4 m/s^2.

So at this point you might be tempted to say “ahah - I get it” ... positive acceleration means you are speeding up while negative acceleration is for slowing down” BUT this is NOT (always) the case! Since we had no problem imagining the car’s speedometer marked off in m/s, it shouldn’t be much more of a stretch of the imagination to consider the car’s speedometer to actually include negative values too. Again - I’ve never seen a car’s speedometer like this, but imagine a speedometer that when the car is put in reverse, the speedometer tells you how fast it is moving “backwards” with a negative reading on the speedometer. Actually, if you had such a device on your car, I wouldn’t want to call it a “speedometer” any more - I’d much rather call it a “velocitometer”. Unfortunately velocitometer isn’t a real word, but I’d still call it that anyway!

Let's consider this car to be stopped. The driver slips it into reverse and steps on the gas. The passenger does his thing with the stopwatch and the now heavily modified "speedometer" (velocitometer). Here are the results:

t	v
0	0 m/s
1 s	-2 m/s
2 s	-4 m/s
3 s	-6 m/s
4 s	-8 m/s
5 s	-10 m/s

Ready for this? According to this information, the car had an *acceleration* of -2 m/s^2. Oh by the way - it was actually *speeding up*. Let's say that the brakes are then gently applied, resulting in this new information from the passenger (who also reset the stopwatch at the same time as the brakes were initially applied):

t	v
0	-10 m/s
1 s	-9 m/s
2 s	-8 m/s
3 s	-7 m/s
4 s	-6 m/s
5 s	-5 m/s

Like it or not, this car had a *positive acceleration*. Its acceleration is +1 m/s^2 ... yet it was actually *slowing down*. Confused? Maybe this summary will help:

Acceleration can be positive or negative, but the sign does not on its own tell you if the object is speeding up or slowing down. Acceleration is a vector. The sign is really just an indication of which direction it is accelerating. If an object accelerates in the same direction that it is moving, it is speeding up; if an object accelerates in the opposite direction from that of its motion, it is slowing down.

Still confused? Maybe this summary of the summary will help:

Velocity	Acceleration	Motion
Positive	Positive	Speeding up
Positive	Negative	Slowing down
Negative	Negative	Speeding up
Negative	Positive	Slowing down

Oh dear ... you're still confused? OK - hopefully, this summary to the summary of the summary will help.

Velocity and Acceleration	Motion
same sign	Speeding up
opposite sign	Slowing down

OK - maybe you're not confused, but you're just not "buying it". It is very tempting for students to think something along the lines of "this is stupid ... I know that accelerate *really* means speeding up - this is just a bunch of crap that hinges on how you are choosing to define the word accelerate". Let me be blunt about this one. If you think that, you are dead wrong. Not a "little big wrong" - nope - you're completely out of it wrong in ways that you're probably not prepared for yet. Unfortunately, you're going to have to take my word for - at least for the moment. As we learn more and more physics (especially in chapters 3 and 4) you will start to see how the "physics meaning" of acceleration is actually brilliant, and the "casual" understanding is woefully naive. How about if I just start planting some seeds here without explaining myself (yet), but I assure you that the following is completely accurate, no arguing about it:

- An object that one person correctly describe as "speeding up" can simultaneously (and correctly) be described by another person as "slowing down" ... the object is not "really" speeding up OR "really" slowing down ... it all depends on how you look at it. Stay tuned for "relative motion" in chapter 3

- Even if the two people mentioned above disagree on whether the object is "speeding up" or "slowing down" ... they will necessarily agree on it's acceleration, as defined by physics.

Still feeling a bit uncertain about things? No worries - we'll soon be introducing equations that nail all of this together.

Freely Falling Objects

It is obvious that falling objects accelerate - that is, they change their velocity as they fall. In "real life" 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 in the acceleration, as does the air pressure, temperature and composition. The truth is that the physics of this type of motion is exceptionally complicated (definitely beyond this course) and so we do something that we will often do in such a case: we ignore some of the complexity by making a simplification of reality. 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 *always assume that air resistance is not involved* in any situation we come across, unless we are specifically instructed to do otherwise - or if we need to analyze a situation in a more "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 *the acceleration of all freely falling bodies (in the same location) is the same*. This "acceleration due to gravity" is so important that you need to memorize its value: all objects freely falling near the earth do so with an acceleration of 9.8 m/s^2. This value actually changes 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 4). It can be very different if on a different planet, or place such as the moon (where the free fall acceleration is about 1.6 m/s^2).

> A "FREELY FALLING OBJECT" IS ONE THAT IS AFFECTED ONLY BY GRAVITY. OBJECTS FREELY FALLING NEAR THE EARTH HAVE AN ACCELERATION OF 9.8 m/s^2 [DOWN].

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. Physics is not based on how popular an idea is. Physics is based on the way the world really works. Remember that. It's probably more important suspect at the moment.

It is very easy to show that heavy objects do not as a rule 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 of a sheet. The full sheet will clearly be twice as heavy as the half-sheet. 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 (though not as easily) that if both are dropped in a vacuum (where there genuinely is no air) both will fall together, at the same rate as falling marshmallows, cats and anvils (although I strongly discourage dropping cats in a vacuum).

> ALL OBJECTS FALL WITH THE SAME ACCELERATION REGARDLESS OF HOW HEAVY THEY ARE, ASSUMING AIR RESISTANCE CAN SAFELY BE IGNORED, AND THAT THEY ARE BEING DROPPED IN THE SAME PLACE

The above is applicable to problems as *we now automatically know the acceleration* of any object that is being pulled on only by gravity. By the way, we default to assuming we are on earth where this acceleration is 9.8 m/s^2 [down] 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 default to choosing up to be positive (and so

a = -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 (**a** = +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 *for the entire time that it is moving.* Convince yourself of this by realizing that while moving up, objects slow down (which is an acceleration opposite the direction of motion: i.e. down), and while moving down they speed up (which is 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 in the downward direction! If it was not accelerating (as many would believe) then its velocity would be constant (that is what 0 acceleration implies) ... constant velocity of zero would mean the object stays up there in the air levitating!

A quick comment about "g"

You may have noticed that at no point so far have I made mention of anything that I labelled with the letter "g". This was very much on purpose, and is one of those differences between "my way" (which is awesome) and most "textbook ways" (which are ~~stupid~~ less awesome ... in my opinion). It turns out that "g" is a very important idea in physics, but it really has no business showing up in chapter 2. I will introduce "g" in chapter 4 - where it belongs. It is pretty nearly a guarantee that you'll come across "g" from your textbook before you get to chapter 4, so let me spend a moment trying to undo the damage that they are causing by doing so:

- It is best to not think of "g" as "the acceleration due to gravity". Calling it this is in my opinion wrong, or misleading at best. We already have a symbol for acceleration: "**a**". Let's just keep using "**a**" for acceleration, regardless of why an object is accelerating (gravity or otherwise).
- Although I do not like it, "g" is sometimes used as if it is a (non-SI) *unit* of acceleration. When used this way, treat is merely as if it was a unit, knowing the following conversion information: 1 g = 9.8 m/s^2. You can ignore this completely, except in a rare problem that asks you to find an acceleration "in g's". Again - I cannot stress this enough - "g" is NOT an acceleration ... we'll clear this up in chapter 4.

Kinematics of Objects moving with Constant Acceleration

I have to confess a little detail that I purposely skipped over earlier. In all of the scenarios involving cars moving earlier in the chapter with the speedometer being observed every second, I kind of assumed (without saying so until now) that the needle on the speedometer swept across the numbers very "smoothly". Actually with real cars, this would not be likely as real cars tend to move in a complicated way as gears change, and engine parameters also vary with speed. Basically, I pretended that the velocity of the car was always changing in a very consistent way. More specifically, I assumed that the cars moved with a constant acceleration.

This is actually a "default assumption" we make about accelerating objects in this course. Basically, the rule we always follow is that we assume the simplest situation that is consistent with the information we have. If we are told an object moves "20 metres in 10 seconds" ... we automatically assume its velocity was constant.

If we are told that a car goes "from zero to 60 km/h in 5 seconds" ... we automatically assume it had a constant acceleration (we cannot assume its velocity was constant as that is not consistent with the information). In fact, it's worth pointing out that although objects very much can move with varying acceleration, we really only consider the "full" kinematics of objects that move with constant acceleration. For objects that move with a constant acceleration (which is to say, the velocity changes in a very "smooth" way, from one value to another), there are exactly 5 kinematic measurements that we focus our attention on:

1. The velocity of the object at the "beginning" - which is to say when we begin our analysis. As we may choose to begin our analysis whenever we want, this beginning velocity will sometimes be zero, and sometimes it won't be zero. Again - there is no single "official" symbol for this idea, but I like to call this the "initial velocity" and so I symbolize it as $\mathbf{v}_i$.

2. The velocity of the object at the "end" of the analysis we are making. Again - we can choose any moment to be the "end" point, and based on this choice, the end velocity may or may not be zero. I call this the "final velocity" and so I symbolize it as $\mathbf{v}_f$.

3. The displacement of the object, which is to say where the object ends up at the end of our analysis relative to where it was at the beginning of our analysis (including direction). Note that "distance" is actually something that we very rarely "care" about! We tend to nearly always focus on displacement and not distance, especially in the case of constant acceleration. We have already introduced the symbol for displacement as **d**.

4. The length of time that we are considering in our analysis. This is Δt.

5. The acceleration of the object as it transitions from the initial velocity to the final velocity. Again - we assume that this is a constant acceleration, and have already introduced its symbol as **a**.

IN THE KINEMATICS OF AN OBJECT WITH CONSTANT ACCELERATION, WE KEEP TRACK OF 5 THINGS: INITIAL VELOCITY ($\mathbf{v}_i$), FINAL VELOCITY ($\mathbf{v}_f$), DISPLACEMENT (**d**), DURATION OF TIME (Δt) AND ACCELERATION (**a**).

Considering that there are 5 things that we keep track of, I'll tell you that it is not a coincidence that there are exactly 5 equations that pertain to constant acceleration. These 5 equations together form a "set" of equations that you will use often. It's well worth memorizing them, even if they will be given to you on your exam. Really - you do NOT want to have to look them up every time you need them.

Before I list off the 5 equations, I have to say a couple of quick things. First off, the textbook only provides four of them. I have no idea why they chose to omit one of them. Second, there is an important "pattern" in the set of equations. You see, each of the 5 equations actually includes *only four* of the 5 things that we are interested in. This means that each equation is *missing one* of the 5 things. This is really, really useful to be aware of.

One of the things that can be difficult for students at first is in choosing which equation to use. Although problems can definitely get tougher, your basic kinematics problems tends to follow a rather unimaginative "recipe" which goes something like this:

- The problem tells you the value of three of the five quantities (Givens)
- The problem asks you to find the value of one of the five quantities (Unknown)

- The problem makes no mention of one of the five quantities

For basic problems like this, if you can "spot" the one piece that is completely "missing" from the problem, you can then choose the equation ... as the one you need is also "missing" that same piece. We'll put this to work in a couple of examples right away, but first let's list off the 5 equations (in no particular order):

The Kinematics Equations for Constant Acceleration

Kinematics Equation	"Missing"
$\vec{v}_f = \vec{v}_i + \vec{a}\Delta t$	$\vec{d}$
$\vec{v}_f^{\,2} = \vec{v}_i^{\,2} + 2\vec{a}\vec{d}$	Δt
$\vec{d} = 0.5(\vec{v}_i + \vec{v}_f)\Delta t$	$\vec{a}$
$\vec{d} = \vec{v}_i\Delta t + 0.5\vec{a}\Delta t^2$	$\vec{v}_f$
$\vec{d} = \vec{v}_f\Delta t - 0.5\vec{a}\Delta t^2$	$\vec{v}_i$

By the way - there is "another" equation that you will almost certainly come across. The equation is $\boldsymbol{a}=\frac{\Delta v}{\Delta t}$. I don't really ever use that equation directly. If you're curious, this equation is redundant with $\vec{v}_f = \vec{v}_i + \vec{a}\Delta t$ (which I consider to be the more useful version of the two). In all fairness though, $\boldsymbol{a}=\frac{\Delta v}{\Delta t}$ really is the equation that *defines* acceleration.

A Note About the Vector Nature of the Kinematics Equations

Notice in the above equations that all of the symbols are vectors except for time. Duration of time is indeed a scalar: it only has a magnitude (how much time), but not a direction. Everything else (velocity, displacement and acceleration) is directional. Again - we will address the directionality with a sign: positive or negative, as described within each problem that we solve. The most common place that students "screw up" in kinematics is in the directionality part. You really need to pay attention to it!

Having said this, I have to say that it is hideously tedious to put all of those little "vector symbols" above the letters. To be clear: they "should" be there - they do serve a purpose (to remind you that these things are vectors) ... but I also have to be honest: I just can't bring myself to do it when I'm "really" solving physics problems. And I'm not alone. Heck - even many textbooks get sloppy and don't bother with the vector notation in these equations. In fact, the official AP formula sheet does not consistently use vector symbols!

So its time for another confession of laziness: from this point forwards, I won't usually bother putting in the vector notation. You can feel free to do the same of course. The one thing that is NOT negotiable is whether or not they are "actually" vectors. They are. You must be conscious of the directionality, as we will see in the examples right away.

One thing might occur to you based on this: If we're going to "skip" out on the vector symbols, how are we going to be able to tell the difference between distance (d) and displacement (**d** or $\vec{d}$). The answer may actually surprise you. Outside of the very beginning of chapter 2, we pretty nearly never care about distance in physics(!) Similarly, we almost never care about speed, as we almost always prefer velocity. It might sound messed up (actually that's because it is) ... but honestly: don't worry about it. You should know the formal difference between distance and displacement, and between speed and velocity, but once we pull up our sleeves and start really doing physics, those differences quickly fade away as speed and distance are not very often used. There are a couple of exceptions in future chapters, but we'll deal with them in good time.

Summary: when you come across a letter "v" in a physics equation, treat it like a vector (velocity). When you come across a "d" in a physics equation, treat it like a vector (displacement). For now, the only exception to this is in a rare case of dealing with the speed and distance of an object in a simple case of v = d/t, in those problems that explicitly use those words.

OK - that's enough for now. Let's get to work with a few examples of how all of this comes together.

E.g. *A car begins from rest. It moves with a constant acceleration of 2 m/s*^{2}*. Find how far it has moved after 5 seconds.*

OK - so this is a completely typical kinematics problem. It's also quite friendly in being very explicit about details that we sometimes have to assume (like the acceleration being constant). It also perfectly fits the mould of "here are 3 givens and 1 unknown" with no mention of the 5th thing that could have been part of the scenario, but isn't. Our "GUESS" method will chew this problem up nicely. I don't think we really need a diagram at all, and as for direction, we'll just use our "Forwards is positive" since we don't really know which way the car is moving. Remember also - I'm not bothering with the vector symbols, but everything here is a vector except for time. I'm also not putting the units into the math, though I am ensuring that I am using nothing but SI units, and so am guaranteed to get the answer also in SI units.

Forwards +

$v_i = 0$ — v_i is zero because it's not moving at the start

$a = 2\ m/s^2$ — the acceleration is given

$\Delta t = 5\ s$ — the duration of time is also given

$d = ?$ — "How far it goes" is displacement, which is the unknown here.

$d = v_i\Delta t + 0.5a\Delta t^2$ — I chose this equation because it doesn't have a v_f in it - which is the one thing that doesn't show up in this problem

$d = 0(5) + 0.5(2)(5)^2$ — Subbing the values in

d = 25 m — And Solving for the answer - done!

e.g. *A ball is dropped. Find how far it moves in the first 3 seconds of falling.*

At first, students sometimes get hung up on a problem like this. After all: there's only one number actually printed in the problem, and so it's tempting to think that maybe we don't have enough information to solve it. However the word "drop" is a loaded word. The word "drop" (as opposed to "thrown") tells us it was released from rest. Also - because of the required assumptions (namely that this object is going to fall with only gravity affecting it ... i.e. air resistance etc. are assumed to be safely ignored), then we automatically know that it will accelerate at the memorized rate of 9.8 m/s^2 [down]. Since the object only moves downward, I'm going to use down as my chosen positive direction, which makes the sign of the acceleration positive. With these ideas in place, let's get to it:

Down +
$v_i = 0$ Since it was "dropped"
$a = 9.8$ m/s^2 Since gravity is the only thing affecting it. It accelerates "down" (positive here)
$\Delta t = 3$ s As given in the problem

$d = ?$ The "unknown"

$d = v_i\Delta t + 0.5a\Delta t^2$ This is the equation that doesn't have v_f in it, which doesn't show up in this problem.

$d = 0(3) + 0.5(9.8)(3)^2$

d = 44.1 m Subbing (above) and solving to get the answer.

e.g. *A ball is dropped. Find how far it moves after 3 seconds.*

Nope - that's not a typo. It's the exact same problem as the previous one. Just to make a point, let me show you what would happen if I chose to let up be positive instead. The acceleration is still going to be down, so if I choose up as my positive reference direction, I'm going to have to make the sign of the acceleration negative. Watch how this plays out:

Up +
$v_i = 0$
$a = -9.8$ m/s^2 It is still accelerating "down" which is now negative since up is positive.
$\Delta t = 3$ s
$d = ?$
$d = v_i\Delta t + 0.5a\Delta t^2$
$d = 0(3) + 0.5(-9.8)(3)^2$
d = -44.1 m

It seems like we have a different answer this time. The previous answer was positive 44.1 m, and now I have negative 44.1 m ... so is it "really" positive or negative? Actually - that's a bogus question. In truth, I got the exact same answer both times. Remember that "d" here is displacement - a vector. The sign is really just an indication of the direction, but it's only meaningful in conjunction with the stated reference direction. In the first solution I used down as positive and got a positive displacement. That means the answer was actually “down 44.1 m”. In the second solution I used up as positive and got a negative displacement, which actually means “down”. In other words, the answer obtained in this solution is actually “down 44.1 m” - the same as the previous solution.

This is crazy important! You really do have to be consistent and careful with your directions. That’s why I actually state my reference in each and every problem. Your textbook may not always be as careful, so you may find yourself wondering sometimes about why a certain something is negative on occasion (or for that matter, why something is positive). In such cases, try to figure out what reference direction they are using (but probably didn’t state) ... that should clear it up.

Also - at least in the case of vector quantities, it means you sometimes have to be flexible on a multiple choice question. On most exam problems, they list all of the answers for vector quantities as positive, or all as negative. Depending on your reference choice, you might agree or disagree on the sign, but it’s really not a problem. When it comes to “matching” your answer to a multiple choice option, be forgiving about the sign, especially if the question itself does not impose a sense of direction (which they usually don’t).

To be very clear: this does NOT apply to any scalar quantity. Scalars as a rule can be positive or negative, but it’s not a matter of “choice”. There should be one clear value for scalars which may be positive or negative depending on the problem. As an example, a temperature of -20°C and a temperature of +20°C are not at all the same thing at all. Temperature is a scalar, and as such the sign has nothing to do with direction.

e.g. *A ball is thrown upwards at a speed of 15 m/s. How long does it take the ball to reach the highest point?*

A pretty straight forward problem, though the first time you come across something like this, you might be a bit confused about “initial” velocity and “final” velocity. Here’s something to consider: *maybe* the initial velocity is zero because you were just holding it (at rest) in your hand, and then you threw it, eventually letting it go at a (final) velocity of 15 m/s. Thinking this way, $v_i = 0$ and $v_f = 15$ m/s.

Actually, that would not be helpful. It’s not really “wrong” ... but it won’t solve our problem. We need to know how high the ball reached after flying through the air. If you were to end your analysis when you let it go, your analysis won’t include the very motion we are looking to investigate. Our analysis needs to include it getting “up there”. In fact, we are going to end our analysis when it gets at the very highest point. By definition, it *stops* rising at the highest point, so we are actually going to need to set $v_f = 0$. What about the initial velocity? It was originally standing still in your hand before you threw it right? Maybe $v_i = 0$ too then?

Again - it’s not technically “wrong” to say that, but if you begin your analysis prior to your making it move, the ball will have had a very complicated motion: it will have *accelerated upwards* for a short time while in your hands and being pushed by them, and then after you let it go, it will have become a “freely falling” object with only gravity acting on it, and so will have an acceleration of 9.8 m/s^2 [down]. Problem is that we can only work mathematically with objects that move with a *constant acceleration* and if your analysis includes both parts (while in your hand AND while flying through the air) ... the acceleration won’t have been constant throughout.

The solution is to begin your analysis at the moment you let it go, and end it when it gets to the highest point. This segment of motion will include the moment needed (at the highest point) and will consist of only one single constant acceleration (free fall acceleration) ... so it’ll work beautifully. Since it moves upwards, I'm going to choose up as my positive reference. This will make the sign of v_i positive, and the acceleration from gravity negative. Here we go:

Up +
$v_i = 15$ m/s
$v_f = 0$
$a = -9.8$ m/s^2
$\Delta t = ?$
$v_f = v_i + a\Delta t$
$\Delta t = (v_f - v_i)/a = (0 - 15) / (-9.8)$
$\Delta t = 1.53$ s

e.g. *Just for fun - let's solve this problem again, this time letting down be positive:*

Down +
$v_i = -15$ m/s
$v_f = 0$
$a = 9.8$ m/s^2
$\Delta t = ?$
$v_f = v_i + a\Delta t$
$\Delta t = (v_f - v_i)/a = (0 - (-15)) / (9.8)$
$\Delta t = 1.53$ s

Wow - we got the exact same answer. Cool - it doesn't "matter" what your choice of reference direction is ... as long as you are consistent with its use!

e.g. *A chemistry book is thrown straight up at 5 m/s (it's a chemistry book as you shouldn't throw physics books) from a height of 2 metres above the floor. The book initially rises, but eventually falls down to the floor. How long does it take for this book to hit the floor from when it was first thrown?*

This is a very straightforward problem, though the math is a bit trickier than the previous ones (you'll see why in a moment). This is a great problem though, because it really helps reinforce the points that I've been making for a while now.

First off - a lot of students get stumped in this kind of problem because they don't know how high the book rises before falling. It's true. We don't know. We could figure this out if we really wanted to, but I have a quick question for you: in our kinematics equations, what does the "d" really stand for?

The answer of course is displacement (not distance). Remember that displacement only cares about where an object ended up from where it began (including direction). It does NOT care about the actual path taken. Give it a moments thought ... this problem actually perfectly fits the mould of "3 givens, 1 unknown" ...

Up +

$v_i = 5$ m/s — Note that v_i is positive since I have chosen up as my reference direction

$a = -9.8\ m/s^2$ — The book is only affected by gravity after being let go, so it accelerates "down"

$d = -2$ m — This is the neat part. Quite simply, the books *ends up* 2 metres *below* where it began. It doesn't matter how high it rose in getting there. Displacement ignores the path taken.

$\Delta t = ?$

$d = v_i\Delta t + 0.5a\Delta t^2$ — I chose this equation as it doesn't have a v_f in it - that's the one thing that doesn't show up in this problem.

$-2 = 5\Delta t + 0.5(-9.8)\Delta t^2$ — Oh crap - this is a "quadratic equation" as it contains our unknown both to the first power (Δt) and also to the second power (Δt^2). If needed, you should review (or perhaps learn) how to solve quadratic equations using the "quadratic formula".

$-2 = 5\Delta t - 4.9\Delta t^2$ — Simplifying the above equation

$4.9\Delta t^2 - 5\Delta t - 2 = 0$ — Putting it in "standard form"

$A = 4.9$; $B = -5$; $C = -2$ — Identifying the coefficients of the quadratic equation

$$\Delta t=\frac{-B\pm\sqrt{B^2-4AC}}{2A}$$ The *memorized* quadratic formula (math - not physics!)

$$\Delta t=\frac{-(-5)\pm\sqrt{(-5)^2-4(4.9)(-2)}}{2(4.9)}$$ Subbing into the quadratic formula

$$\Delta t=\frac{5\pm 8.0125}{9.8}$$ Simplifying

$$\Delta t=\frac{5-8.0125}{9.8} \text{ or } \Delta t=\frac{5+8.0125}{9.8}$$ Two solutions: one for addition; one for subtraction in place of ±

$\Delta t = -0.307$ s or $\Delta t = 1.33$ s — Solving for each of the two solutions.

Reject $\Delta t < 0$ ... Final Answer: **$\Delta t = 1.33$ s** — In this context, a negative solution is not physically meaningful.

Motion Graphs

I know it seems like this chapter has been going on forever, but there is still one more piece to it. Until this point, we have focussed mostly on algebraic (equation-based) methods for interpreting and computing motion based measurements. We now see how graphs are a powerful tool to add to our kinematic tool kit.

Slope

The slope of a straight line is a measure of how "slanted" the line is. A slope of zero means that it is not at all slanted (i.e. it is horizontal). As the slope increases from zero, the line becomes increasingly slanted, pointing "up to the right". A vertical line has an undefined slope which may be interpreted as being infinite in slope. A line that slopes "down to the right" has a negative slope. In general the slope of a line on a standard "math style" graph (on which the vertical axis is labelled y and the horizontal axis is labelled x), may be calculated as "rise over run" which may be written as $\frac{y_2 - y_1}{x_2 - x_1}$. By the way - a handy symbol that I've avoided so far is the Greek letter "delta" which is written as a small triangle (Δ). Delta is used in math to represent the "change" in a value. As an example, "Δx" literally means "x_2 - x_1" and so the equation for slope can actually be written in a rather neat way as $\frac{\Delta y}{\Delta x}$.

That's all fine and good for math, but physics graphs do not typically use x and y. In their places we most often see variable quantities such as time, position, velocity etc. that we are interested in analysing. This means that we can have a "position-time graph" on which the vertical axis (which gets listed first) reveals the position of an object, while the horizontal axis indicates time. Note that there is no "x" nor is there a "y" on such a graph. The slope would be found by the same methods as before, but using position in place of y and time in place of x.

While you are certainly familiar with the slope of a line, you may not be familiar with the slope of a curve. By definition, a curve has a slope that changes: it may be "steep" in some places, and "level" in others. An in-depth investigation of the slope of a curve requires calculus, so we are necessarily going to do this a bit "loosely". For our purposes, we are going to claim that the slope of a curve can be found at any particular point by regarding the curve in the immediate vicinity of the point of interest to be a very short straight line. The slope of the curve at that point can be found by extending this short, straight line to be longer in order for us to find the slope of it. The slope of this extended straight line (called a "tangent line") will be the slope of the curve at the point it came from. Note that the units of the slope are those of the vertical axis divided by those of the horizontal axis.

Area

Turning now to the notion of area, we need to make three extensions to what you already know. First, in the context of graphs, the "area of a graph" is defined to be the area confined between the plot and the horizontal axis, with vertical lines sectioning off the bit of it under investigation. Second, the area is regarded as being positive if it is above the horizontal axis; negative if below. Third, the units of this area are generally NOT what you would expect for area. The units come from multiplying the horizontal and vertical axes' units.

In this chapter, there are two basic kinds of "motion graph" that are introduced. They are position-time graphs and velocity-time graphs.

It is important to realize that position-time graphs (which will be abbreviated as p-t graphs) reveal more than just position and time. If two points on a p-t graph are considered, then the “rise” is actually a displacement while the “run” is the duration of time for this displacement. Connecting these two points with a straight line (even if the graph itself is not straight) therefore reveals the *average* velocity over this duration of time. Of course if the graph itself was a straight line then this slope will be the actual velocity. In the case of a curved graph, we can draw a tangent line (described above) at a point on the graph. The slope of the tangent line would be the *instantaneous velocity* at that moment.

Velocity-time graphs (abbreviated v-t graphs) can be analysed in much the same way. In this case however, it is found that slopes reveal accelerations. v-t graphs offer even more versatility than p-t graphs, as we may additionally determine areas on them, which represent displacements.

Of course, motion graphs are just the beginning. You should be conscious of the general strategies introduced here and know that they can be applied to other types of graphs later in physics, and indeed everywhere else too. Always consider the slope and/or area of a graph. While they can always be determined mathematically, they are not always meaningful.

THE SLOPE OF A POSITION-TIME GRAPH INDICATES VELOCITY; THE SLOPE OF A VELOCITY-TIME GRAPH INDICATES ACCELERATION; THE AREA CONTAINED IN A VELOCITY-TIME GRAPH INDICATES DISPLACEMENT.

Chapter 2 Summary

At last! You just made it to the end of chapter 2! Here's a quick reminder of what you should have gotten out of this chapter:

- ☐ You can use the GUESS method to solve problems
- ☐ You can use the simplified approach to Sig Figs for generic problem solving
- ☐ You know what the words "mechanics" "kinematics" and "dynamics" mean
- ☐ You know the difference between "distance" and "displacement"
- ☐ You know the difference between "speed" and "velocity"
- ☐ You can work with the equation "$v = d/\Delta t$" including the variations of it (namely the scalar / vector versions, and the instantaneous / average versions)
- ☐ You know what acceleration means, including its units
- ☐ You know that acceleration is a vector, and how its sign is really directional
- ☐ You know that freely falling objects are only affected by gravity and that the acceleration of a freely falling object is unaffected by things like the objects mass; the acceleration of a freely falling object near the earth is 9.8 m/s^2
- ☐ You know that "g" should NOT be used at all in chapter 2, with the rare exception of it being treated like a unit, in those cases that a problem explicitly brings it up that way. Otherwise, we'll save "g" for chapter 4 where it belongs.
- ☐ You know the 5 equations for kinematics of an object that has a constant acceleration and how to use them in problems
- ☐ You know that you have to be very careful with directionality in kinematics problems, and that you should state your reference direction in each problem (e.g. "Up +")
- ☐ You know how to work with motion graphs, and in particular know that the slope of a p-t graph is velocity; the slope of a v-t graph is acceleration; the area contained in a v-t graph is displacement.

Chapter 2 Problems

Here are just a few problems to get you working right away. This is NOT enough! After doing these problems, you should tackle the problems that are in your textbook. The answers to these problems appear at the end of this chapter.

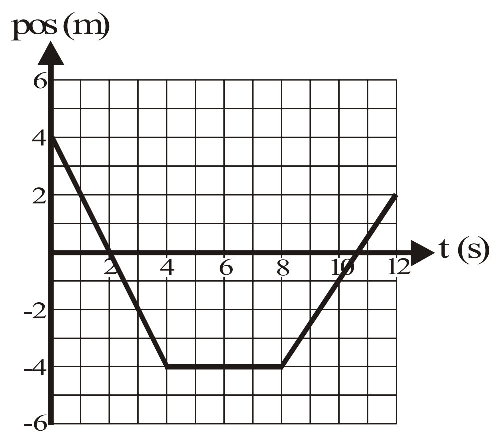
1. An object moves 3 metres west then 4 metres north. For this whole motion (a) what was its distance (b) what was its displacement?

2. If the motion described in the previous problem took a total of 12 seconds, then (a) what was the object's average speed (b) what was the object's average velocity?

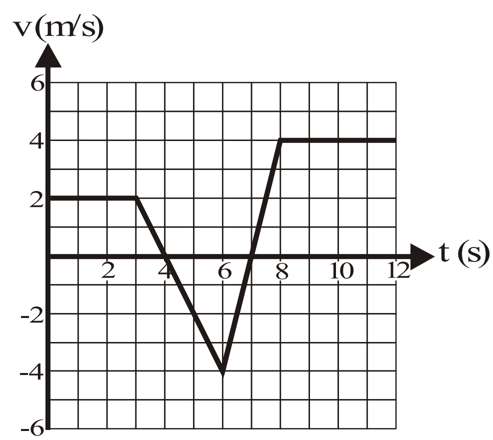
3. A car is driven at 50 km/h for 2 hours. It then is driven for 300 km at 100 km/h. Find its average speed for this whole trip. Answer in km/h.

4. A Shakespearean novel is thrown straight up into the air. When it is released, it is moving at 15 m/s. How long does it take for this book to reach a point that is 2 metres above the point it was released from?

5. For the given position-time graph, describe the motion both numerically and descriptively. Then construct a velocity-time graph for the same motion. "Right" should be taken as positive.



6. For the given velocity-time graph, describe the motion both numerically and descriptively. Then construct a position-time graph for the same motion. "Right" should be taken as positive. Note: the object here has an initial position of -10 m.



Answers to Chapter 2 Problems

1. a) 7m b) 5 m @53.1° N of W

2. a) 0.583 m/s b) 0.417 m/s @53.1° N of W

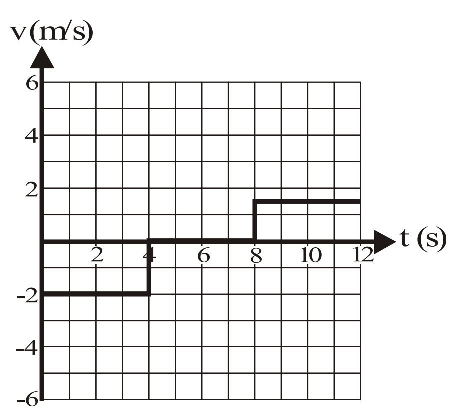
3. 80 km/h

4. Two solutions: 0.14 s and 2.92 s
Note: both of these are actually correct. The book rises from the point of release. 0.14 seconds later it is at the point 2 metres above where it was released. It then continues to rise, reaches a maximum height and then falls back down. 2.92 s after it was thrown, it is *again* at the point 2 metres above the point of release. In other words: it literally reaches this point twice ... once on the way up, and once on the way down.

5. Description: The object begins at a position 4 metres right of the reference position. It is moving left with a constant speed. At a time of 2 s, it passes by the reference position, but keeps going. At a time of 4 seconds it reaches a position 4 metres left of the reference position and immediately stops when it gets there. It remains at rest at that position for 4 seconds, at which time (8 seconds into the motion) there is a dramatic change: it is suddenly moving to the right with a constant speed. It again passes the reference position at some point between 10 and 11 seconds. 12 seconds into the motion it is still moving to the right and is at a position 2 metres right of the reference position.

time interval	speed and direction	displacement	Position at end of interval	acceleration
0-2 s	constant, 2 m/s [left]	4 m [left]	0 m	0
2-4 s	constant, 2 m/s [left]	4 m [left]	-4 m	0
4-8 s	constant, 0	0	-4 m	0
8-12 s	constant, 1.5 m/s [right]	6 m	2 m	0

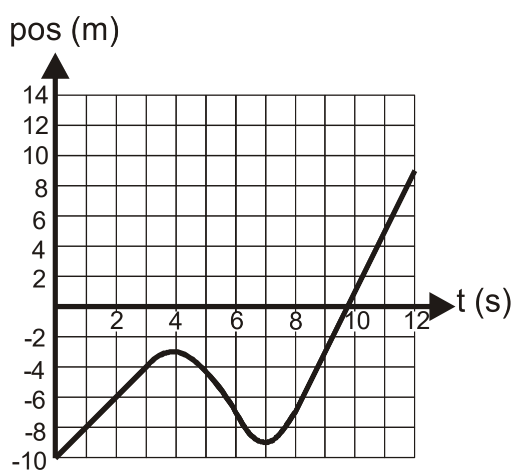
Here is the associated velocity time graph:



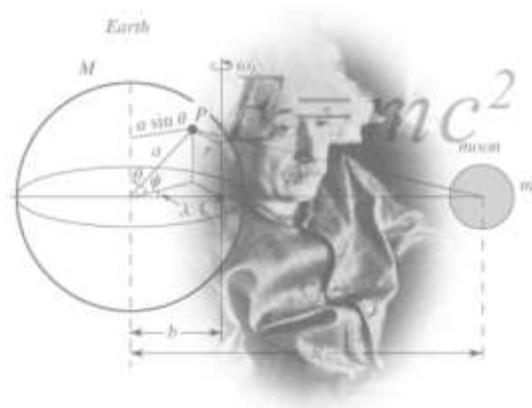
6. Description: Object begins at a position of 10 m left of reference position. It has a constant velocity to the right, which it maintains for 3 seconds. At a time of 3 seconds it begins to slow down with a constant leftward acceleration which it maintains for 3 seconds. At a time of 4 seconds it was momentarily at rest, but as the acceleration continued, it started to speed up while moving left. It reaches a maximum speed of 4 m/s, moving left at a time of 6 seconds, but then starts to slow down, as its acceleration suddenly changes to a new (but again constant) acceleration to the right, which it maintains for an additional 2 seconds, by which time it is moving right at 4 m/s. It then stops accelerating, maintaining a constant velocity of 4 m/s to the right for an additional 4 seconds.

time	speed and direction	Displacement	Position at end of interval	acceleration
0-3 s	constant 2 m/s [right]	6 m	-4 m	0
3-4 s	slowing down from 2 m/s to 0 [right]	1 m	-3 m	- 2m/s^2
4-6 s	speeding up from 0 to 4 m/s [left]	-4 m	-7 m	- 2m/s^2
6-7 s	slowing down from 4 m/s to 0 [left]	-2 m	-9 m	4 m/s^2
7-8 s	speeding up from 0 to 4 m/s [right]	2 m	-7 m	4 m/s
8-12 s	constant 4 m/s [right]	16 m	9 m	0

Here is the associated position time graph:



Appendix B



Welcome to AP Physics 1! It is a college level physics course that is fun, interesting and challenging on a level you've not yet experienced. This summer assignment will review all of the prerequisite knowledge expected of you. There are 7 parts to this assignment. It is quantity not the difficulty of the problems that has the potential to overwhelm, so do it over an extended period of time. it should not take you any longer than a summer reading book assignment. By taking the time to review and understand all parts of this assignment, you will help yourself acclimate to the rigor and pacing of AP Physics 1. Use the book if you need to, but really this is all stuff you already know how to do (basic math skills). It is VERY important that this assignment be completed ***individually***. It will be a total waste of your time to copy the assignment from a friend. The summer assignment will be due the first day of class. Good luck! ☺

Part 1: Scientific Notation and Dimensional Analysis

Many numbers in physics will be provided in scientific notation. You need to be able read and simplify scientific notation. (**This section is to be completed without calculators…all work should be done by hand.)** Get used to no calculator! All multiple choice portions of tests will be completed without a calculator.

Express the following the numbers in scientific notation. Keep the same unit as provided. ALL answers in physics need their appropriate unit to be correct.

1. 7,640,000 kg

2. 8327.2 s

3. 0.000000003 m

4. 0.0093 km/s

Often times multiple numbers in a problem contain scientific notation and will need to be reduced by hand. Before you practice, remember the rules for exponents.

When numbers are multiplied together, you *(add / subtract)* the exponents and *(multiply / divide)* the bases.

When numbers are divided, you *(add / subtract)* the exponents and *(multiply / divide)* the bases.

When an exponent is raised to another exponent, you *(add / subtract / multiply / divide)* the exponent.

Using the three rules from above, simplify the following numbers in proper scientific notation:

5. $(3x10^{6})\cdot(2x10^{4}) =$

6. $(1.2x10^{4}) / (6x10^{-2}) =$

7. $(4x10^{8})\cdot(5x10^{-3}) =$

8. $(7x10^{3})^{2} =$

9. $(8x10^{3}) / (2x10^{5}) =$

10. $(2x10^{-3})^{3} =$

Fill in the power and the symbol for the following unit prefixes. Look them up as necessary. These should be **memorized** for next year. Kilo- has been completed as an example.

Prefix	Power	Symbol
Giga-		
Mega-		
Kilo-	10^3	k
Centi-		
Milli-		
Micro-		
Nano-		
Pico-		

Not only is it important to know what the prefixes mean, it is also vital that you can convert between metric units. If there is no prefix in front of a unit, it is the base unit which has 10^0 for its power, or just simply "1". Remember if there is an exponent on the unit, the conversion should be raised to the same exponent as well.

Convert the following numbers into the specified unit. Use scientific notation when appropriate.

1. 24 g = _______ kg
2. 94.1 MHz = _______ Hz
3. 6 Gb = ________ kb
4. 640 nm = ________ m
5. 3.2 m^2 = ________ cm^2
6. 40 mm^3 = _______ m^3
7. 1 g/cm^3 = _______ kg/m^3
8. 20 m/s = _______ km/hr

For the remaining scientific notation problems you may use your calculator. It is important that you know how to use your calculator for scientific notation. The easiest method is to use the "EE" button. An example is included below to show you how to use the "EE" button.

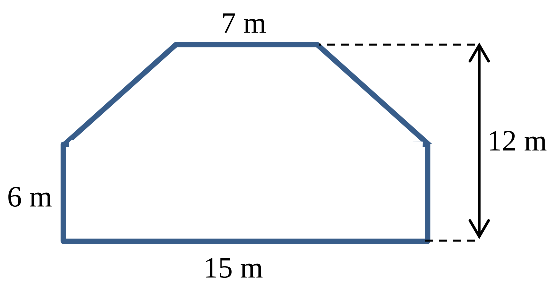
Ex: $7.8x10^{-6}$ would be entered as 7.8"EE"-6

9. $(3.67x10^{3})(8.91x10^{-6})$ =
10. $(5.32x10^{-2})(4.87x10^{-4})$ =
11. $(9.2x10^{6})$ / $(3.6x10^{12})$ =
12. $(6.12x10^{-3})^{3}$

Part 2: Geometry

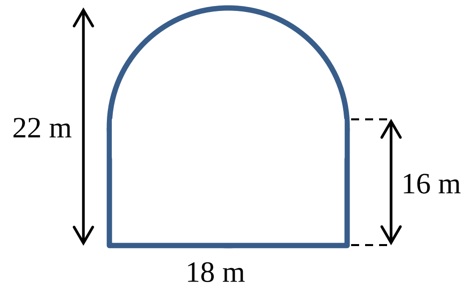
Calculate the area of the following shapes. It may be necessary to break up the figure into common shapes.

1.



Area = _________

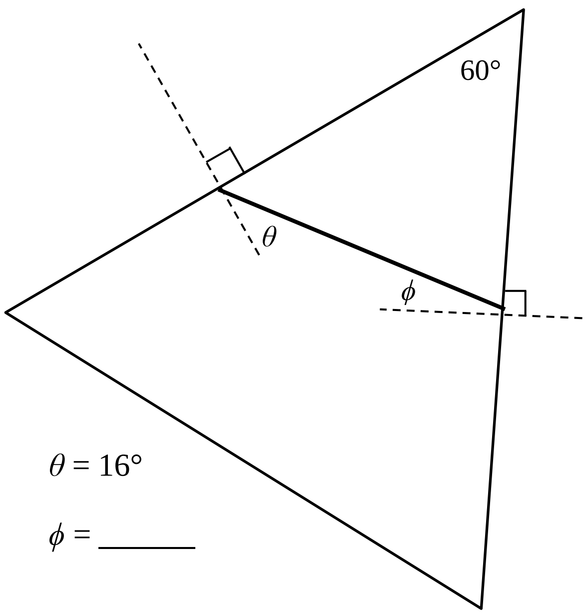
2.



Area = _________

Calculate the unknown angle values for questions 3-6.

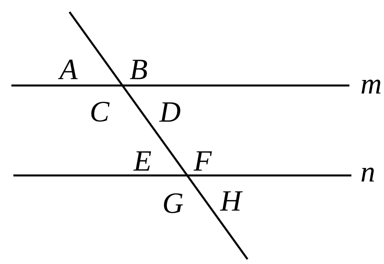
3.



$\theta = 16°$

ϕ = _______

4.

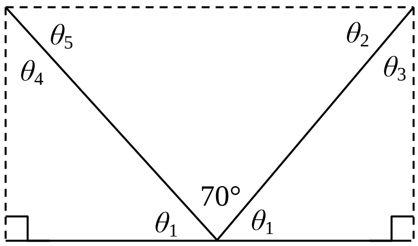


Lines *m* and *n* are parallel.

$A =$ 75° $B =$ ______ $C =$ ______ $D =$ ______

$E =$ ______ $F =$ ______ $G =$ ______ $H =$ ______

5.



$\theta_1 =$ ______

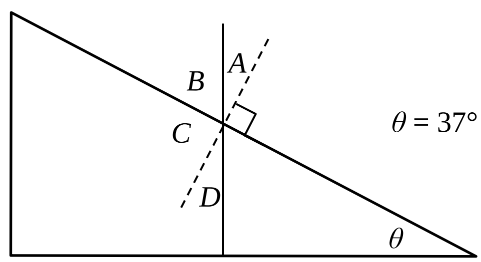
$\theta_2 =$ ______

$\theta_3 =$ ______

$\theta_4 =$ ______

$\theta_5 =$ ______

6.



$\theta = 37°$

$A =$ ______ $B =$ ______

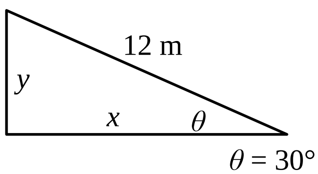
$C =$ ______ $D =$ ______

Part 4: Trigonometry

Write the formulas for each one of the following trigonometric functions. Remember SOHCAHTOA!

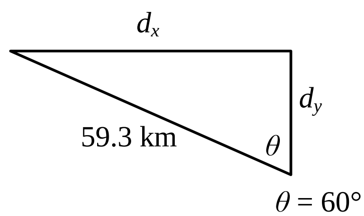
$\sin\theta =$ $\cos\theta =$ $\tan\theta =$

Calculate the following unknowns using trigonometry. Use a calculator, but show all of your work. Please include appropriate units with all answers. (Watch the unit prefixes!)

1.


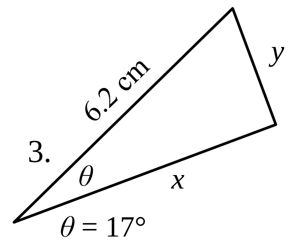
$y =$ ________

$x =$ ________

2.


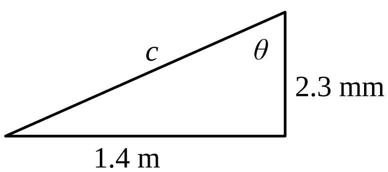
$d_x =$ _______

$d_y =$ _______

3.


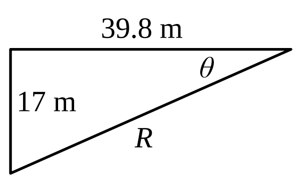
$x =$ ______

$y =$ ______

4.


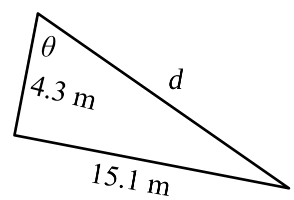
$c =$ _______

$\theta =$ _______

5.


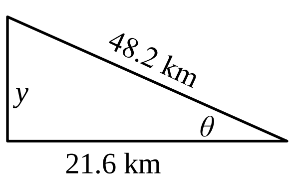
$R =$ _______

$\theta =$ _______

6.


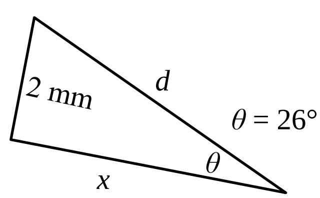
$d =$ _______

$\theta =$ _______

7.


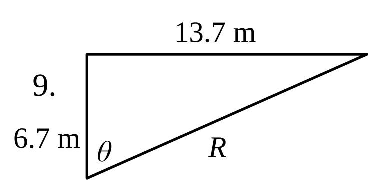
$y =$ _______

$\theta =$ _______

8.


$x =$ _______

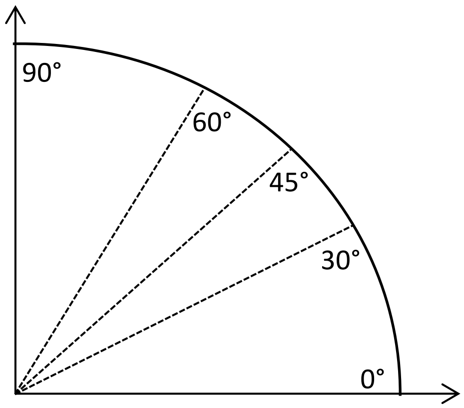
$d =$ _______

9.


$R =$ _______

$\theta =$ _______

You will need to be familiar with trigonometric values for a few common angles. Memorizing this unit circle diagram in degrees or the chart below will be very beneficial for next year in both physics and pre-calculus. How the diagram works is the cosine of the angle is the x-coordinate and the sine of the angle is the y-coordinate for the ordered pair. Write the ordered pair (in fraction form) for each of the angles shown in the table below



θ	$\cos\theta$	$\sin\theta$
0°		
30°		
45°		
60°		
90°		

Refer to your completed chart to answer the following questions.

10. At what angle is sine at a maximum?

11. At what angle is sine at a minimum?

12. At what angle is cosine at a minimum?

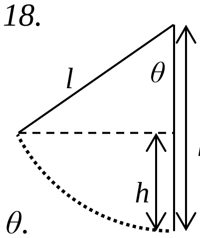
13. At what angle is cosine at a maximum?

14. At what angle are the sine and cosine equivalent?

15. As the angle increases in the first quadrant, what happens to the cosine of the angle?

16. As the angle increases in the first quadrant, what happens to the sine of the angle?

Use the figure below to answer problems 17 and 18.



17. Find an expression for h in terms of l and θ.

18. What is the value of h if l = 6 m and θ = 40°?

Part 5: Algebra

Solve the following (almost all of these are extremely **easy** – it is *important* for you to work *independently*). Units on the numbers are included because they are essential to the concepts, however they do not have any *effect* on the actual numbers you are putting into the equations. In other words, the units do not change how you do the algebra. Show every step for every problem, including writing the original equation, all algebraic manipulations, and substitution! You should practice doing all algebra *before* substituting numbers in for variables.

Section I: *For problems 1-5, use the three equations below:*

$$v_f = v_0 + at \qquad x_f = x_0 + v_0 t + \frac{1}{2}at^2 \qquad v_f^2 = v_0^2 + 2a(x_f - x_0)$$

1. Using equation (1) solve for t given that v_0 = 5 m/s, v_f = 25 m/s, and a = 10 m/s^2.

2. a = 10 m/s^2, x_0 = 0 m, x_f = 120 m, and v_0 = 20 m/s. Use the second equation to find t.

3. v_f = - v_0 and a = 2 m/s^2. Use the first equation to find t / 2.

4. How does each equation simplify when a = 0 m/s^2 and x_0 = 0 m?

Section II: *For problems 6 – 11, use the four equations below.*

$$\Sigma F = ma \qquad f_s \leq \mu_s N$$
$$f_k = \mu_k N \qquad F_s = -kx$$

5. If ΣF = 10 N and a = 1 m/s^2, find m using the first equation.

6. Given $\Sigma F = f_k$, m = 250 kg, μ_k= 0.2, and N = 10m, find a.

7. ΣF = T – 10m, but a = 0 m/s^2. Use the first equation to find m in terms of T.

8. Given the following values, determine if the third equation is valid. $\Sigma F = f_s$, m = 90 kg, and a = 2 m/s^2. Also, μ_s= 0.1, and N = 5 N.

9. Use the first equation in Section I, the first equation in Section II and the givens below, find ΣF. m = 12 kg, v_0 = 15 m/s, v_f = 5 m/s, and t = 12 s.

10. Use the last equation to solve for F_s if k = 900 N/m and x = 0.15 m.

Section III: *For problems 12, 13, and 14 use the two equations below.*

$$a = \frac{v^2}{r} \qquad \tau = rFsin\theta$$

11. Given that v is 5 m/s and r is 2 meters, find a.

12. Originally, a = 12 m/s^2, then r is doubled. Find the new value for a.

13. Use the second equation to find θ when τ = 4 Nm, r = 2 m, and F = 10 N.

Section IV*: For problems 15 – 22, use the equations below.*

$$K = \frac{1}{2}mv^2 \qquad W = F(\Delta x)cos\theta \qquad P = \frac{W}{t}$$

$$\Delta U_g = mgh \qquad U_s = \frac{1}{2}kx^2 \qquad P = Fv_{avg}cos\theta$$

14. Use the first equation to solve for K if m = 12 kg and v = 2 m/s.

15. If ΔU_g = 10 J, m = 10 kg, and g = 9.8 m/s^2, find h using the second equation.

16. $K = \Delta U_g$, g = 9.8 m/s^2, and h = 10 m. Find v.

17. The third equation can be used to find W if you know that F is 10 N, Δx is 12 m, and θ is 180°.

18. Given U_s = 12 joules, and x = 0.5 m, find k using the fourth equation.

19. For P = 2100 W, F = 30 N, and θ = 0°, find v_{avg} using the last equation in this section.

Section V: *For problems 23 – 25, use the equations below.*

$$p = mv \qquad F\Delta t = \Delta p \qquad \Delta p = m\Delta v$$

20. p is 12 kgm/s and m is 25 kg. Find v using the first equation.

21. "Δ" means "final state minus initial state". So, Δv means $v_f - v_i$ and Δp means $p_f - p_i$. Find v_f using the third equation if p_f = 50 kgm/s, m = 12 kg, and v_i and p_i are both zero.

22. Use the second and third equation together to find v_i if v_f = 0 m/s, m = 95 kg, F = 6000 N, and Δt = 0.2 s.

Section VI*: For problems 26 – 28 use the three equations below.*

$$T_s = 2\pi\sqrt{\frac{m}{k}} \qquad T_p = 2\pi\sqrt{\frac{l}{g}} \qquad T = \frac{1}{f}$$

23. T_p is 1 second and g is 9.8 m/s^2. Find l using the second equation.

24. m = 8 kg and T_s = 0.75 s. Solve for k.

25. Given that $T_p = T$, g = 9.8 m/s^2, and that l = 2 m, find f (the units for f are Hertz).

Section VII*: For problems 29 – 32, use the equations below.*

$$F_g = -\frac{GMm}{r^2} \qquad U_g = -\frac{GMm}{r}$$

26. Find F_g if $G = 6.67 \times 10^{-11}$ m^3 kg^{-1} s^{-2}, $M = 2.6 \times 10^{23}$ kg, $m = 1200$ kg, and $r = 2000$ m.

27. What is r if $U_g = -7200$ J, $G = 6.67 \times 10^{-11}$ m^3 kg^{-1} s^{-2}, $M = 2.6 \times 10^{23}$ kg, and $m = 1200$ kg?

28. Use the first equation in Section IV for this problem. $K = -U_g$, $G = 6.67 \times 10^{-11}$ m^3 kg^{-1} s^{-2}, and $M = 3.2 \times 10^{23}$ kg. Find v in terms of r.

29. Using the first equation above, describe how F_g changes if r doubles.

Section VIII: *For problems 36 – 41 use the equations below.*

$$V = IR \qquad R = \frac{\rho l}{A}$$

$$I = \frac{\Delta Q}{t} \qquad R_S = (R_1 + R_2 + R_3 + \cdots + R_i) = \Sigma R_i$$

$$P = IV \qquad \frac{1}{R_P} = \left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \cdots + \frac{1}{R_i}\right) = \sum_i \frac{1}{R_i}$$

30. Given $V = 220$ volts, and $I = 0.2$ amps, find R (the units are ohms, Ω).

31. If $\Delta Q = 0.2$ C, $t = 1$s, and $R = 100$ Ω, find V using the first two equations.

32. $R = 60$ Ω and $I = 0.1$ A. Use these values to find P using the first and third equations.

33. Let $R_S = R$. If $R_1 = 50$ Ω and $R_2 = 25$ Ω and $I = 0.15$ A, find V.

34. Let $R_P = R$. If $R_1 = 50$ Ω and $R_2 = 25$ Ω and $I = 0.15$ A, find V.

35. Given $R = 110$ Ω, $l = 1.0$ m, and $A = 22\times 10^{-6}$ m^2, find ρ.

Part 6: Graphing and Functions

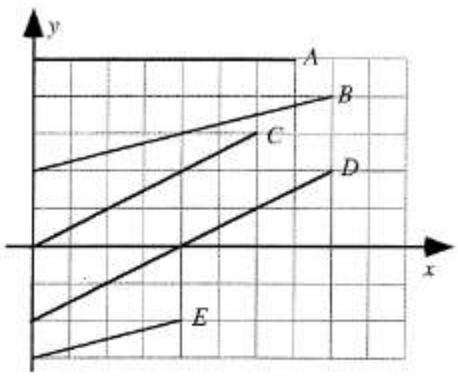
A greater emphasis has been placed on conceptual questions and graphing on the AP exam. Below you will find a few example concept questions that review foundational knowledge of graphs. Ideally you won't need to review, but you may need to review some math to complete these tasks. At the end of this part is a section covering graphical analysis that you probably have not seen before: *linear transformation*. This analysis involves converting any non-linear graph into a linear graph by adjusting the axes plotted. We want a linear graph because we can easily find the slope of the line of best fit of the graph to help justify a mathematical model or equation.

Key Graphing Skills to remember:

1. Always label your axes with appropriate units.
2. Sketching a graph calls for an estimated line or curve while plotting a graph requires individual data points AND a line or curve of best fit.
3. Provide a clear legend if multiple data sets are used to make your graph understandable.
4. Never include the origin as a data point unless it is provided as a data point.
5. Never connect the data points individually, but draw a single smooth line or curve of best fit
6. When calculating the slope of the best fit line you must use points from your line. You may only use given data points IF your line of best fit goes directly through them.

Conceptual Review of Graphs

Shown are several lines on a graph.

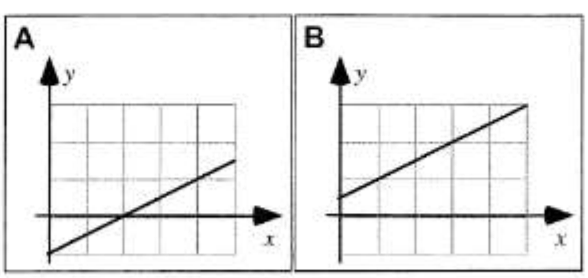


Rank the slopes of the lines in this graph.

					OR			
1 Greatest	2	3	4	5 Least		All the same	All zero	Cannot determine

Explain your reasoning.

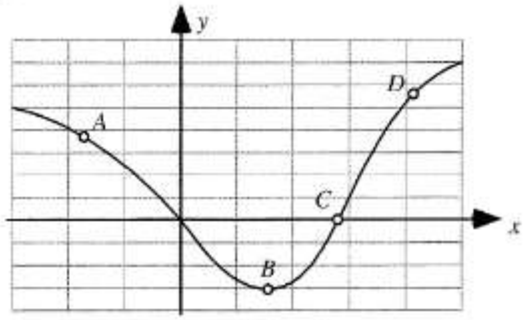
Shown are two graphs.



Is the slope of the graph (i) ***greater in Case A*****, (ii)** ***greater in Case B*****, or (iii)** ***the same in both cases?*** _____

Explain your reasoning.

Four points are labeled on a graph.



Rank the slopes of the graph at the labeled points.

☐	☐	☐	☐	OR	☐	☐	☐
1 Greatest	2	3	4 Least		All the same	All zero	Cannot determine

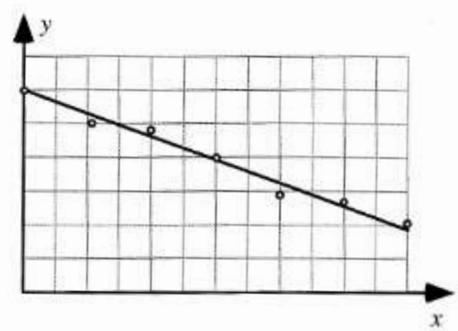
Explain your reasoning.

A1-WWT22: Line Data Graph—Interpretation

A student makes the following claim about some data that he and his lab partners have collected:

"Our data show that the value of y decreases as x increases. We found that y *is inversely proportional to* x.*"*

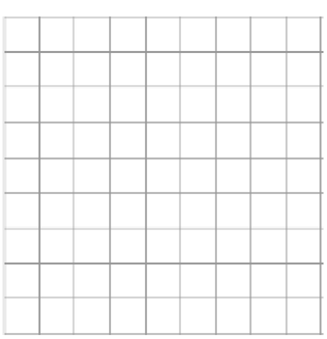
What, if anything, is wrong with this statement? If something is wrong, identify and explain how to correct all errors. If this statement is correct, explain why.

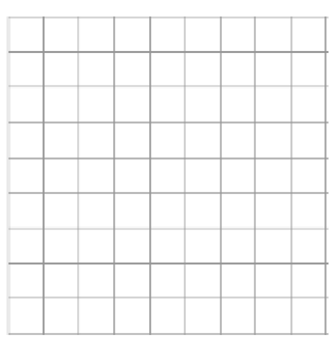


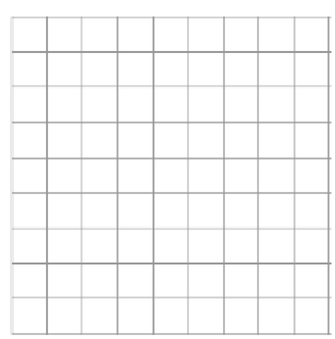
Linear and Non-Linear Functions

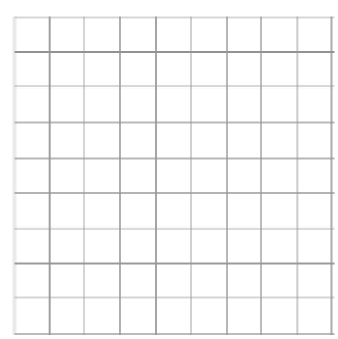
You must understand functions to be able linearize. First let's review what graphs of certain functions looks like. Sketch the shape of each type of *y vs. x* function below. *k* is listed as a generic constant of proportionality.

Linear $y = kx$ Inverse $y = {}^{k}/_{x}$ Inverse Square $y = {}^{k}/_{x^2}$ Power $y = kx^2$









You will notice that only the linear function is a straight line. We can easily find the slope of our line by measuring the rise and dividing it by the run of the graph or calculating it using two points. The value of the slope should equal the constant *k* from the equation.

Finding *k* is a bit more challenging in the last three graphs because the slope isn't constant. This should make sense since your graphs aren't linear. So how do we calculate our constant, *k*? We need to transform the non-linear graph into a linear graph in order to calculate a constant slope. We can accomplish this by transforming one or both of the axes for the graph. The hardest part is figuring out which axes to change and how to change them. The easiest way to accomplish this task is to solve your equation for the constant. Note in the examples from the last page there is only one constant, but this process could be done for other equations with multiple constants. Instead of solving for a single constant, put all of the constants on one side of the equation. When you solve for the constant, the other side of the equation should be in fraction form. This fraction gives the rise and run of the linear graph. Whatever is in the numerator is the vertical axis and the denominator is the horizontal axis. If the equation is not in fraction form, you will need to inverse one or more of the variables to make a fraction. First let's solve each equation to figure out what we should graph. Then look below at the example and complete the last one, a sample AP question, on your own.

State what should be graphed in order to produce a linear graph to solve for *k*.

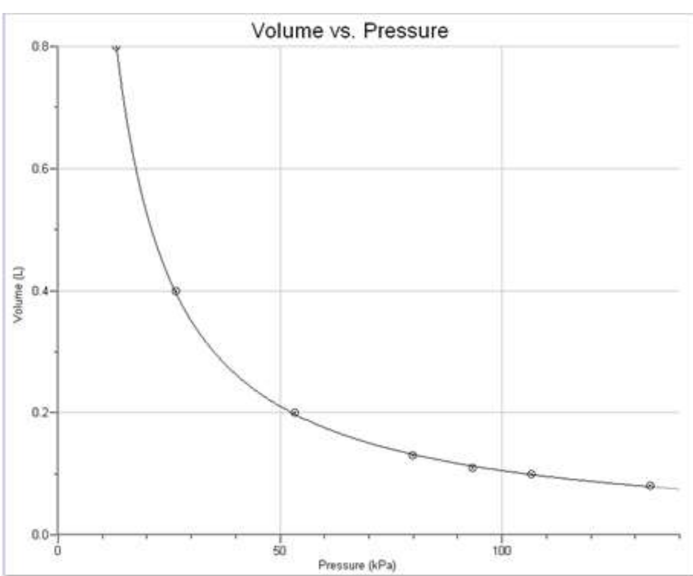
Inverse Graph Vertical Axis:______________________ Horizontal Axis: ______________________

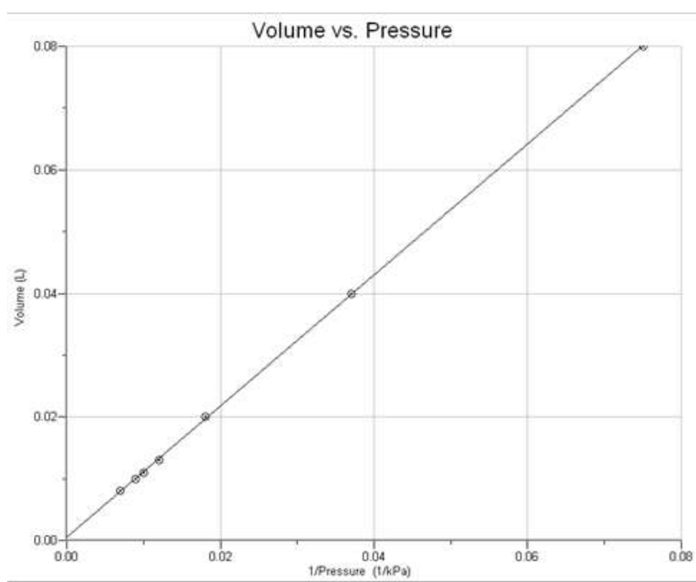
Inverse Square Graph Vertical Axis:______________________ Horizontal Axis: ______________________

Power (Square) Graph Vertical Axis:______________________ Horizontal Axis: ______________________

Chemistry Example

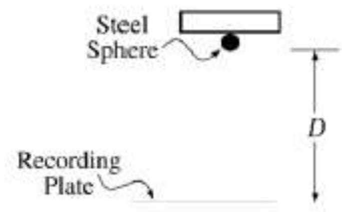
Let's look at an equation you should remember from chemistry. According to Boyle's the law, an ideal gas obeys the following equation $P_1V_1 = P_2V_2 = k$. This states that pressure and volume are inversely related, and the graph on the left shows an inverse shape. Although the equation is equal to a constant, the variables are not in fraction form. One of the variables, pressure in this case, is inverted. This means every pressure data point is divided into one to get the inverse. The graph on the left shows the linear relationship between volume V and the inverse of pressure 1/P. We could now calculate the slope of this linear graph.



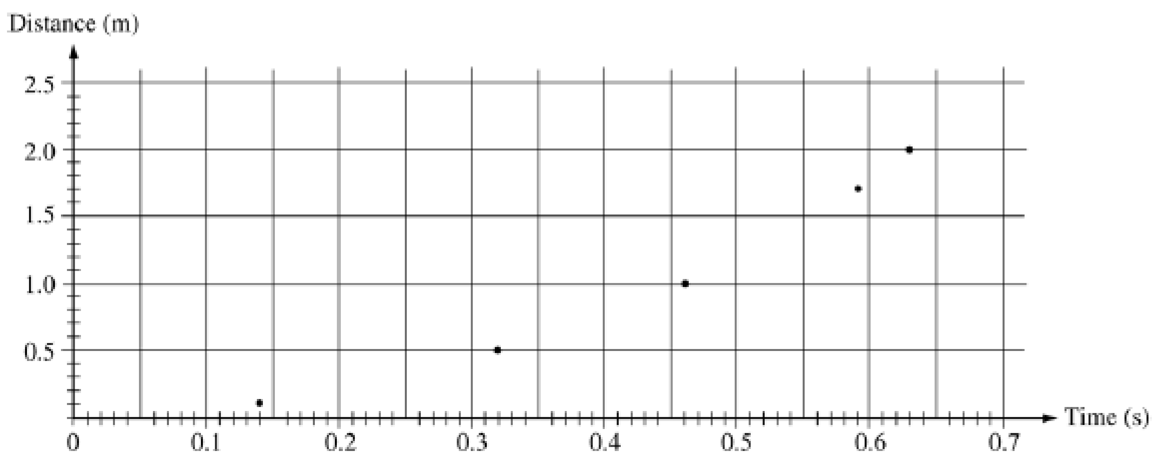


Sample AP Graphing Exercise

A steel sphere is dropped from rest and the distance of the fall is given by the equation $D = \frac{1}{2}gt^2$. D is the distance fallen and t is the time of the fall. The acceleration due to gravity is the constant known as g. Below is a table showing information on the first two meters of the sphere's descent.

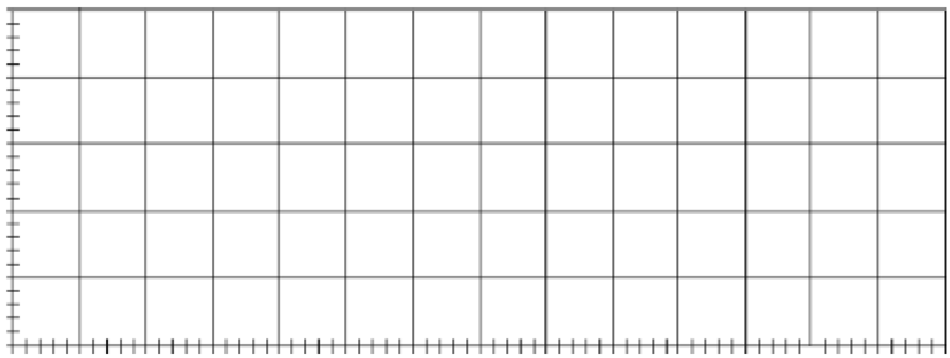


Distance of Fall (m)	0.10	0.50	1.00	1.70	2.00
Time of Fall (s)	0.14	0.32	0.46	0.59	0.63



a) Draw a line of best fit for the distance vs. time graph above.
b) If only the variables D and t are used, what quantities should the student graph in order to produce a linear relationship between the two quantities?

c) On the grid below, plot the data points for the quantities you have identified in part (b), and sketch the straight-line fit to the points. Label your axes and show the scale that you have chosen for the graph.



d) Calculate the value of g by using the slope of the graph.

Part 7: Scalars and Vectors Preview

Hooray for the Internet! Watch the following two videos. For each video, summarize the content Mr. Khan is presenting in three sentences. Then, write at least one question per video on something you didn't understand or on a possible extension of the elementary concepts he presents here.

http://www.khanacademy.org/science/physics/v/introduction-to-vectors-and-scalars

Summary 1

http://www.khanacademy.org/science/physics/v/visualizing-vectors-in-2-dimensions

Summary 2

Congratulations! You're finished! That wasn't so bad was it? *Trust me*… the blood, sweat, and tears it took to get through all of those problems will make everything later on a lot easier. Think about it as an investment with a guaranteed return.

This course is a wonderful opportunity to grow as a critical thinker, problem solver and great communicator. Don't believe the rumors- it is not impossibly hard. It ***does*** *require hard work, but so does anything that is worthwhile. You would never expect to win a race if you didn't train. Similarly, you can't expect to do well if you don't train academically. AP Physics is immensely rewarding and exciting, but you do have to take notes, study, and read the book (gasp!). I guarantee that if you do what is asked of you that you will look back to this class with huge sense of satisfaction! I know I can't wait to get started…*

Let's learn some ***SCIENCE****!!!*

AP® CollegeBoard

Workbook | 2021

AP® Physics 1

Workbook | 2021

Unit 1 - Kinematics

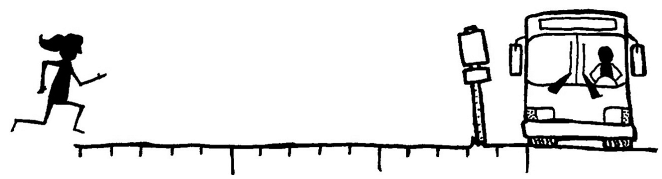
NAME ______________________ DATE ______________

Scenario

Angela is running to the bus 15 *meters away.*

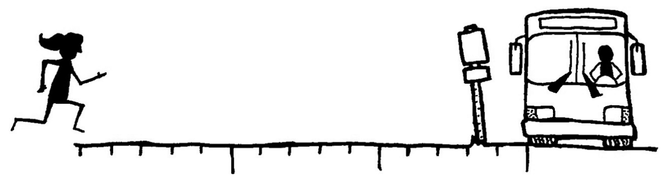
Using Representations

PART A: On the diagram to the right, label Angela's position with zero meters and label the position of the bus door 15 meters. Label the marks between Angela and the bus with appropriate position values.



Based on the labels along the axis in the diagram above, what direction (left or right) should be labeled positive? Label this direction on the diagram using an arrow (vector).

PART B: If the positive direction was labeled as the opposite direction of what you chose in Part A, think about how the locations of the labels for 0 meters and 15 meters would change. Relabel the diagram at right, with the positive direction pointing the opposite way as in Part A. Include position values along the bottom of the scale.



Argumentation

PART C: You are asked to make a ***claim*** about the *physical meaning* of Angela's *displacement* in Part B. Fill in the blanks below to complete the Claim, Evidence, and Reasoning paragraph.

Evidence: When Angela gets to the bus, her position is ________ (number) meters.

Angela's initial position was ________ (number) meters.

Reasoning: Displacement is equal to the final position minus the initial position.
$\Delta x = x_f - x_i$ or $\Delta x = x - x_f$

Claim: Therefore, Angela's displacement is ________ (number) meters minus ________ (number) meters which equals ________ (number) meters.

Data Analysis

PART D: How does the displacement in Part C compare to the displacement in Part A?

____

____

PART E: If Angela ran to the bus and back to where she started, what distance would she travel? Compare that to her displacement.

____

____

____

____

NAME ______________________________ DATE ______________

Scenario

Angela is running at 3 m/s *toward the bus* 15 m *away.*

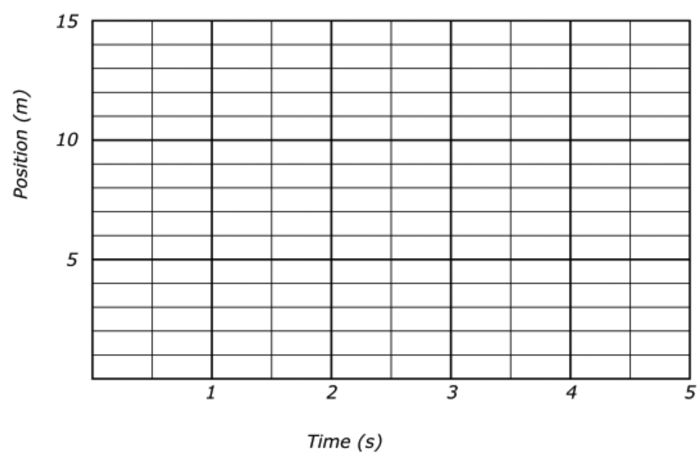
Using Representations

PART A: Below is a table of Angela's position at each second. Complete the table. Then, on the diagram of Angela and the bus, create a ***motion map*** of Angela's position at every second. Do this by marking with a dot where Angela is at every second.

X	Time (s)	0	1	2	3	4	5
Y	Position (m)	0	3	6			

PART B: Another way to represent Angela's motion is by creating a ***position vs. time graph.*** Finish filling out the data table above and then mark Angela's position at every second on the graph. (Plot the data points with solid filled-in dots.)

Sketch a best-fit line through the data points by drawing a single continuous straight line through the points. (Sketch the best-fit line as close as possible to all points and as many points above the line as below.)



Quantitative Analysis

PART C: Calculate the slope of the line you drew in Part B by choosing two points ***on the line*** and filling in the equation below. (Choose two locations on the line that will be used to calculate the slope. Circle these two places on the line—remember DO NOT use data points from the table.)

$$slope = \frac{rise}{run} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{(\quad)\,\text{m} - (\quad)\,\text{m}}{(\quad)\,\text{s} - (\quad)\,\text{s}} = \frac{\_\_\_\ \text{m}}{\text{s}} = (\quad)$$

The slope of a position vs. time graph represents the ______________ (physical quantity). (Hint: Check units!)

Using the equation for a line ($y = mx + b$), write an equation (including units) for the position vs. time line given above. (Remember that m is the slope and b is the vertical intercept.)

_______ = _______ _______ + _______
letter   number   letter   number

Write a more general equation for Angela's motion using standard physics symbols (x, v, t).

_______ = _______ _______
letter   letter   letter

NAME ______________________ DATE ______________

Scenario

A toy company claims to have developed two toy car models which they call A and B, where the average speed of each car is identical ($0.50 \pm 0.02\,\frac{m}{s}$). Each group of students is given two toy cars (one of each model), metersticks, and stopwatches and is asked to test the toy company's claim.

Experimental Design

PART A: The students decide that they need to collect distance and time data for each car to test the company's claim. The students design a procedure.

Cross out any extraneous steps and order the remaining procedural steps:

________ Turn the car on and release along the measured path.

________ Gather equipment.

________ Repeat to reduce error.

________ Measure and record the time the car took to travel the 2 meters with a stopwatch.

________ Measure a 2-meter-long path on the floor.

________ Draw a data table in your notebook.

Data Analysis

PART B: Given is a data set collected by students in the class. Based on these data, what conclusion should the students make about the hypothesis that the two cars, A and B, have the same speed?

Lab Group Number	CAR A Speed	CAR B Speed
1	0.45 m/s	0.54 m/s
2	0.46 m/s	0.52 m/s
3	0.42 m/s	0.56 m/s
4	0.43 m/s	0.55 m/s
5	0.74 m/s	0.23 m/s
6	0.44 m/s	0.54 m/s
AVERAGE	**0.49 m/s**	**0.49 m/s**

________ The cars have the same average speed.

________ The cars have different average speeds.

Explain your choice in one short sentence.

____

____

Experimental Design

PART C: The students decide that additionally they want to test the toy company's claim that the car's speed is constant throughout the motion. How, if at all, does the experimental procedure from Part A need to be modified to verify that the car's instantaneous speed is constant?

________ Angela thinks they should use a motion sensor to collect speed vs. time data. If the graph of speed vs. time is horizontal with a zero slope, the instantaneous speed is constant.

________ Blake thinks that they should use photogates positioned at the beginning and end of the 2-meter-long track to determine the instantaneous speed of the cart. The students measure the length of the cart and divide this length by the time recorded by the photogate to determine the instantaneous speed.

Identify which student's procedure will provide evidence for the claim that the instantaneous speed of the cart is constant.

____

____

____

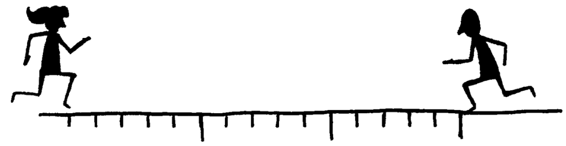
____

____

NAME ______________________ DATE ______________

Scenario

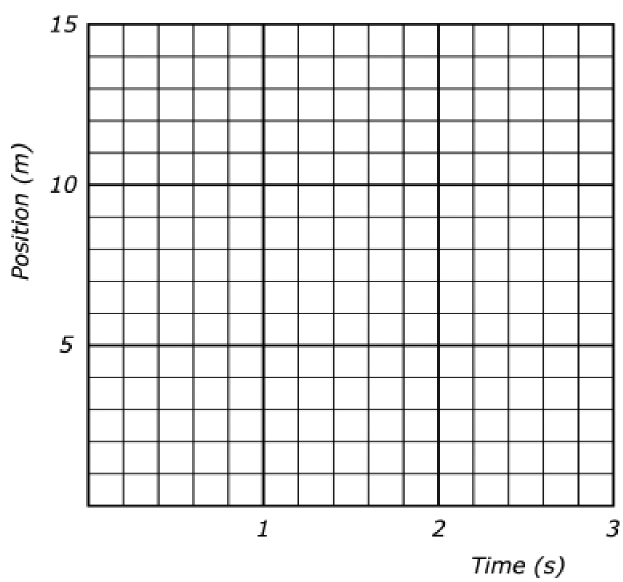
Angela and Blake are running toward each other from 15 m away. At time $t = 0$ s, Angela runs to the right at 5 m/s, and Blake runs to the left at 3 m/s.



Using Representations

PART A: Complete the table and draw a position vs. time graph for Angela and Blake for the first 3 seconds. Make each graph a different color and include a key.

Time *(seconds)*	***Angela's Position*** *(meters)*	***Blake's Position*** *(meters)*
0		
1		
2		
3		



Quantitative Analysis

PART B: Calculate the ***slope*** of the line you drew in Part A for Angela by choosing two points on the line and filling in the equation below:

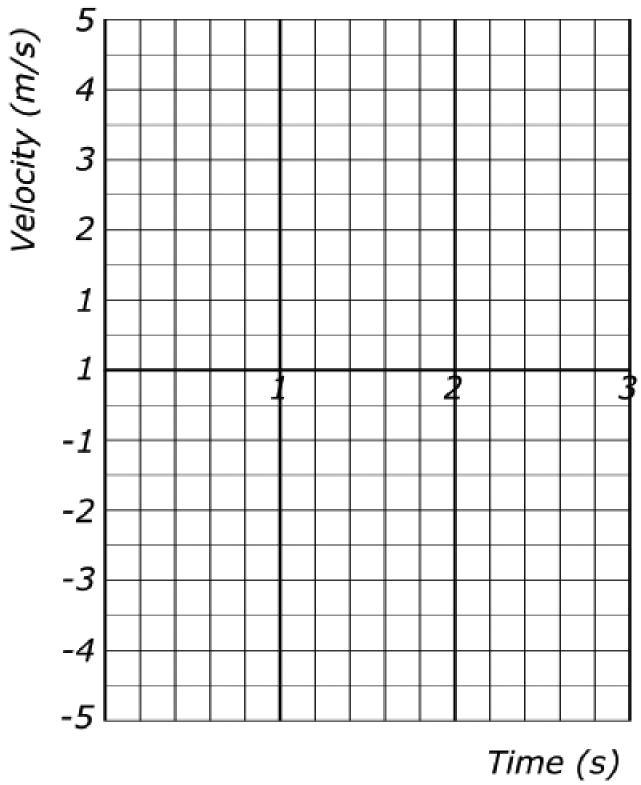
$$slope = \frac{rise}{run} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{(\quad)\,\text{m} - (\quad)\,\text{m}}{(\quad)\,\text{s} - (\quad)\,\text{s}} = \frac{\rule{1em}{0.4pt}\ \text{m}}{\text{s}} = (\quad)$$

PART C: Calculate the ***slope*** of the line you drew in Part A for Blake by choosing two points on the line and filling in the equation below:

$$slope = \frac{rise}{run} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{(\quad)\,\text{m} - (\quad)\,\text{m}}{(\quad)\,\text{s} - (\quad)\,\text{s}} = \frac{\rule{1em}{0.4pt}\ \text{m}}{\text{s}} = (\quad)$$

Using Representations

PART D: Based on the slopes you calculated in Parts B and C, sketch a velocity vs. time graph for Angela and Blake. Make each graph a different color and include a key.



Argumentation

PART E: Carlos makes the following claim about the intersection point of the two lines on the position vs. time graph in Part A. "The point on the position vs. time graph where the two lines cross represents the time when Angela and Blake are at the same position and traveling at the same velocity."

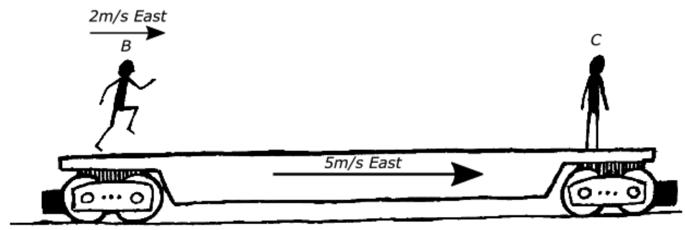
The student's claim is partially correct. Fill in the blanks of the following statement using evidence from the graph to correct the student's claim.

Claim: I agree that the ______________ (physical quantity) is the same because Angela and Blake do have the same ______________ (physical quantity) of ________ (number) meters at ________ (number) seconds. However, I do not agree that they have the same ______________ (physical quantity) because the slope of one line is ________ (number) m/s and the slope of the other line is ________ (number) m/s.

NAME ______________________ **DATE** ______________

Scenario

Blake and Carlos are playing on a train while Angela watches. While the train passes Angela, it is traveling at 5 m/s to the east. At this time, Blake is running at 2 m/s east relative to the train toward Carlos (who is taking a break). (All speeds given for Blake are relative to the train.)



Using Representations

PART A: Identify and label a direction to be positive. In the sketch above, label the positive direction.

Sketch a motion map based on Angela's measurement of Blake's motion.

Sketch a motion map based on Carlos's measurement of Blake's motion.

Data Analysis

PART B: Use the diagram in Part A to determine Blake's speed relative to Angela.

____

____

PART C: Blake now turns around and runs at 2 m/s west.

Use the diagram at right to determine Blake's velocity relative to Angela's.

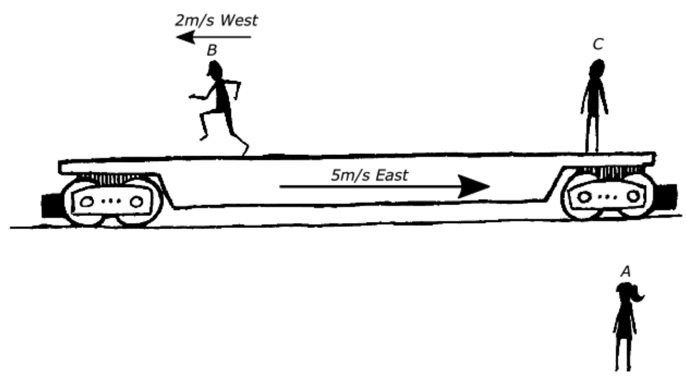
____

____

____

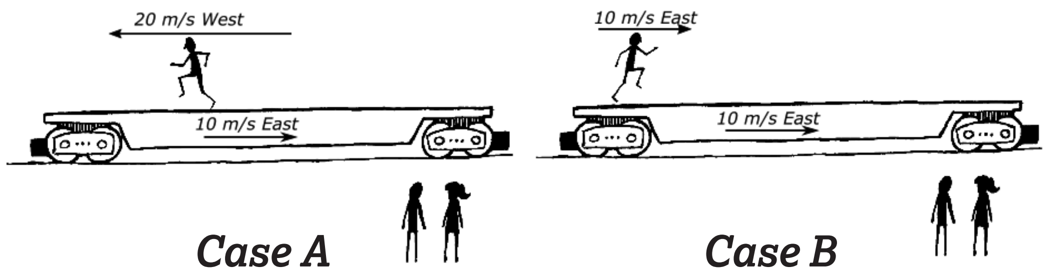
____

____



Argumentation

PART D: In both cases shown below, Blake is running on a train as it travels. In which case is Blake's speed relative to the ground the greatest?



Circle the correct parts of each student's argument.

Blake: I'm running the fastest in Case A. Therefore, I will appear to be moving fastest relative to the ground. Who cares what the train is doing?

Carlos: No, the train does matter, but since $20 + 10$ is greater than $10 + 10$, you are right that in Case A is where Blake is the fastest.

Angela: Blake is running fastest relative to the ground in Case B because Blake's velocity and the train's velocity are in the same direction and add up to 20 m/s east; but in Case A, Blake's velocity is in the opposite direction of the train and they add up to 10 m/s west.

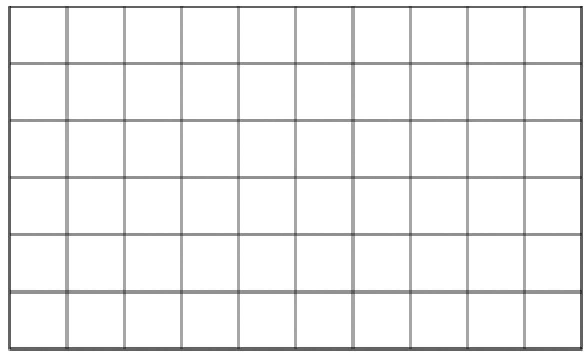
NAME ______________________________ **DATE** ______________

Scenario

Carlos places a constant motion vehicle on the ground and releases it so that the vehicle travels down the hall at 5 m/s *in a straight line for* 10 *seconds.*

Using Representations

PART A: Scale and label the axes on the graph to the right. Draw a velocity vs. time graph of the constant motion vehicle for the first 10 seconds of its motion.



Argumentation

PART B: Collect evidence about the physical meaning of the slope of the graph that could be used to support a claim. Fill in the blanks below.

Evidence: The slope of the velocity vs. time graph

is equal to ________ (number) ________ (units). ________ (units) is also the unit

for ________________ (physical quantity).

PART C: **Claim:** The constant motion vehicle will travel a distance of 50 meters during the 10-second time interval.

Collect evidence about the physical meaning of the area under the line on the graph that can be used to support the claim above. Using the equation for the area of a rectangle (*Area* = *length* × *width*), write an equation (including units) for the area of the rectangle between the velocity vs. time line and the x-axis between $t = 0$ and $t = 10$ seconds.

Evidence: The area under the line of the velocity vs. time graph is equal to ________ (number) ________ (units) × ________ (number)

________ (units) = ________ (number) ________ (units). This area is also known as the ________________ (physical quantity) of the vehicle.

Reasoning: Fill in the blanks of the following statement.

The claim makes sense because if the constant motion vehicle is traveling at a velocity of

________ (number) m/s, then each second it will move a distance of ________ (number) meters. After 2 seconds, the

vehicle has moved ________ (number) meters. After 3 seconds, it has moved ________ (number) meters. After

________ (number) seconds, it has moved 25 meters.

Quantitative Analysis

PART D: Rewrite the equation for the area of a rectangle (*Area* = *length* × *width*) using the symbols and numbers (with units) from the graph in Part A between $t = 0$ and $t = 10$ seconds.

________ (letter) = ________________ (number (with units)) ________ (letter)

The area under a velocity vs. time graph represents the ________________ (physical quantity).
(Hint: Use the units.)

NAME ______________________________ **DATE** ______________

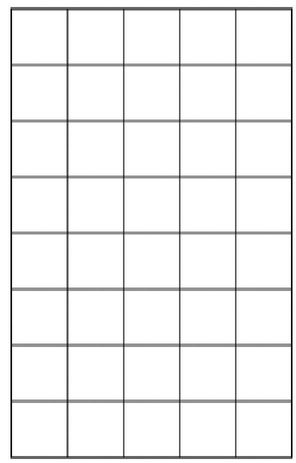
Scenario

A car traveling in a straight line to the right starts from rest at time $t = 0$.
At time $t = 2$ s, the car is traveling at 4 m/s. At $t = 4$ s the car is traveling at 8 m/s.

Using Representations

PART A: Scale and label the axes on the graph to the right. Using the data table below, plot a velocity vs. time graph for the car for the first 4 seconds it is traveling.

Time *(s)*	***Speed*** *(m/s)*
0	0
1	2
2	4
3	6
4	8



Argumentation

PART B: **Evidence:** Calculate the slope of the velocity vs. time graph in Part A using two points on the line (NOT data points).

$$slope = \frac{rise}{run} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{(\quad)\frac{m}{s} - (\quad)\frac{m}{s}}{(\quad)s - (\quad)s} = \_\_\_\_ \frac{m}{s^2} = (\qquad)$$

Claim: Use the evidence above to make a claim by filling in the following blanks:

The slope of the velocity vs. time graph is equal to ________ (number) ______ (unit). ______ (unit) is also the unit for ____________________ (physical quantity).

Quantitative Analysis

$$Area = \tfrac{1}{2}bh$$

PART C: Rewrite the equation for the area of a triangle ($Area = \frac{1}{2}$ *base* $\times$ *height*) using the symbols and numbers (with units) from the graph in Part A between $t = 0$ and $t = 4$ seconds.

______ (letter) $= \frac{1}{2}$ ____________ (number (with units)) ____________ (number (with units))

Write a more general equation for the car using standard physics symbols (x, v_f, and t).

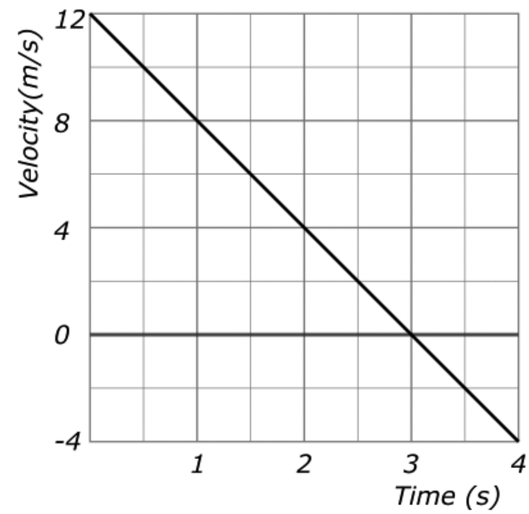
______ (letter) $= \frac{1}{2}$ ______ (letter) ______ (letter)

The area under a velocity vs. time graph represents the ____________________ (physical quantity). (Hint: Check units!)

NAME ______________________________ DATE ______________

Scenario

The motion of a car, starting from position $x = 0$ m is modeled in the velocity vs. time graph at right.



Quantitative Analysis

PART A: Using the equation for a line ($y = mx + b$), write an equation (including units) for the velocity vs. time line given above.

______ (letter) = ______________ (number (with units)) ______ (letter) + ______________ (number (with units))

Write a more general equation for the motion of the car using standard physics symbols (x, v_x, t, a_x).

The slope of a velocity vs. time graph represents the ______________ (physical quantity).

Argumentation

PART B: Carlos makes the following claim about the motion of the car.

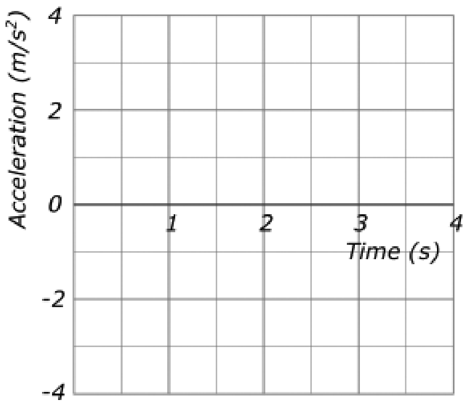
Carlos: “The car is slowing down for the entire distance it travels because the slope of the line is always negative and never changes.

Evidence: Fill in the blanks and circle the appropriate choices to complete the following statement of evidence to disprove Carlos’s claim:

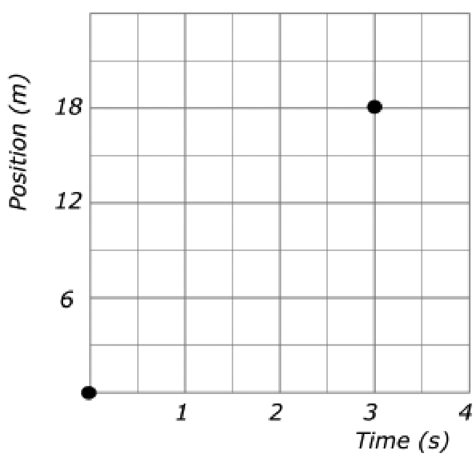
The car starts with an initial velocity of ________ (number) m/s and is (slowing down/speeding up) for the first 3 seconds and (slowing down/speeding up) for the last second. At 3 seconds, the car’s motion changes from traveling (in the positive direction/in the negative direction) to traveling (in the positive direction/in the negative direction). The horizontal intercept represents the ______________ (physical quantity) when the ______________ (physical quantity) of the car is equal to ________ (number). The car accelerates constantly with a magnitude of ________ (number) m/s^2 because the ______________ (mathematical term) of the line never changes.

Using Representations

PART C: Use the graph in Part A to draw an acceleration vs. time graph for the motion represented above.



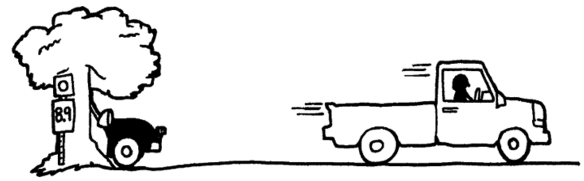
PART D: Use the graph in Part A to draw a position vs. time graph for the motion represented above. The position vs. time graph will pass through the two dots plotted for you.



NAME ______________________________ DATE ______________

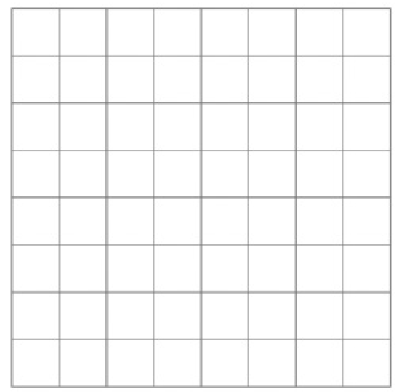
Scenario

A truck is traveling at a constant speed of $20\ \text{m/s}$ *through a school zone. At time* $t = 0$ *seconds, he passes a hidden police car that is at rest. Five seconds after the truck passes, the police car begins accelerating at a constant rate of* $2\ \text{m/s}^2$ *in order to catch the truck.*



Using Representations

PART A: On the axis at right, sketch and label graphs of the velocity of the truck and the police car as functions of time for the first 40 seconds after the truck passes the hidden police car. Use different colors or different lines (e.g., dashed vs. solid) to differentiate between the truck and the police car. Include a key.



Data Analysis

PART B:

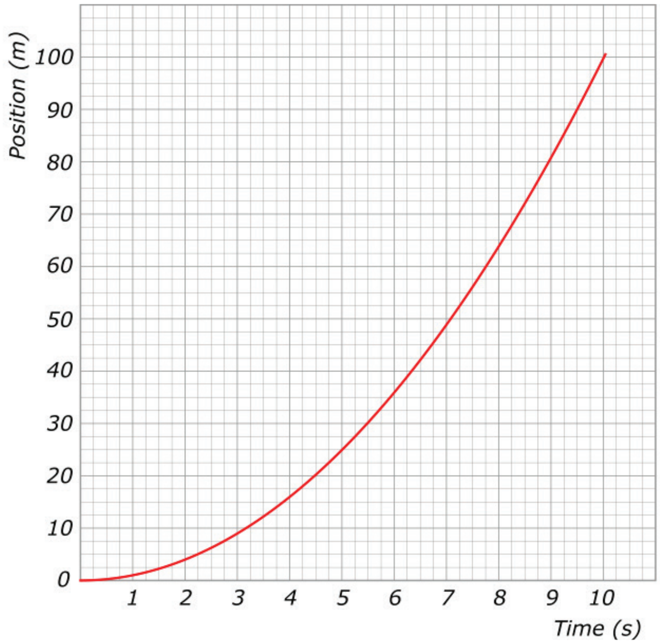
i. Using the graph you made in Part A, determine the time at which the speed of the truck is equal to the speed of the police car. Mark this time as t_1.

ii. How will the positions of the police car and the truck compare when they have the same speed and why?

PART C: Explain in a short sentence or two how you could use the graph you made in Part A to determine the time at which the truck and the police car are in the same location.

Argumentation

PART D: Angela and Blake are discussing Carlos's graph of position as a function of time for the police car.



Angela says, "Since the police car is accelerating, the graph of position vs. time should be a curve, showing that the speed is changing. The graph of position vs. time for the police car is correct.

Blake says, "I don't see how that can be. The police car waits for 5 seconds before moving. The graph shouldn't start at (0, 0) but at (5, 0)."

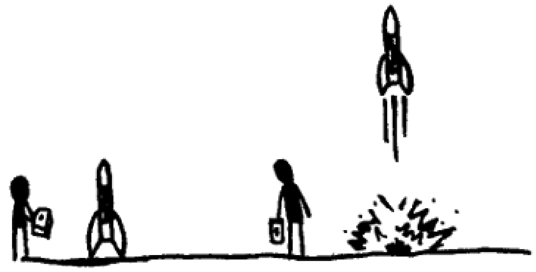
Which aspects of Angela's reasoning, if any, are correct? Support your answer with evidence.

Which aspects of Blake's reasoning, if any, are correct? Support your answer with evidence.

NAME ______________________________ **DATE** ____________

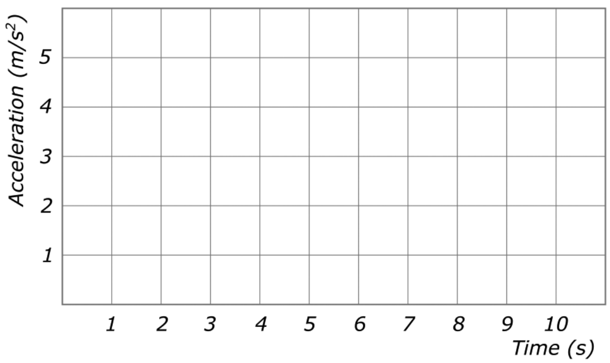
Scenario

A rocket fires its engines to launch straight up from rest with an upward acceleration of $5\ \mathrm{m/s^2}$ *for 10 seconds. After this time, the engine shuts off, and the rocket freely falls straight down back to Earth's surface.*

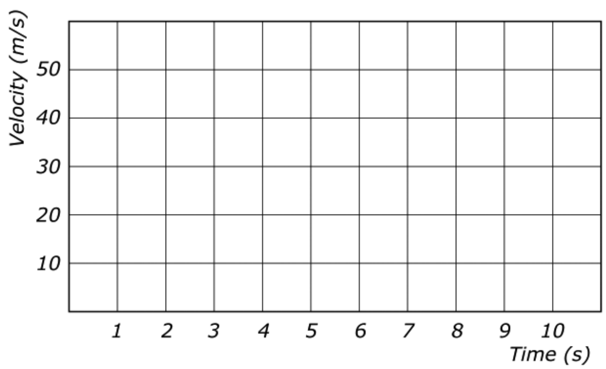


Using Representations

PART A: Sketch a graph of the acceleration as a function of time from $t = 0$ seconds to $t = 10$ seconds.



PART B: Sketch a graph of the velocity as a function of time from $t = 0$ seconds to $t = 10$ seconds.



Data Analysis

PART C: From the graph drawn in Part B, determine the velocity of the rocket after the initial 10 seconds of travel.

The velocity of the rocket at the end of 10 seconds is ________________.

PART D: From the graph drawn in Part B, determine the height of the rocket after 10 seconds.

Height = ____

Argumentation

PART E: Make a claim about the numerical value of the acceleration of the rocket 10.1 seconds after firing when the rocket engines have been completely shut off. (Fill in the blanks.)

The acceleration of the rocket 10.1 seconds after it was launched is ________________.

Use the definition of free fall to explain your reasoning for your claim in Part E.

PART F: 10.1 seconds after the rocket was launched, indicate whether the rocket moving upward or downward.

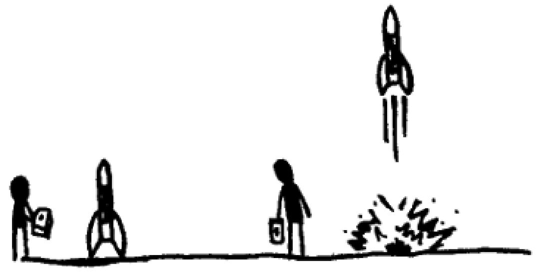
______ Upward ______ Downward

Choose one piece of evidence to support your claim and write it below.

NAME ______________________________ **DATE** ______________

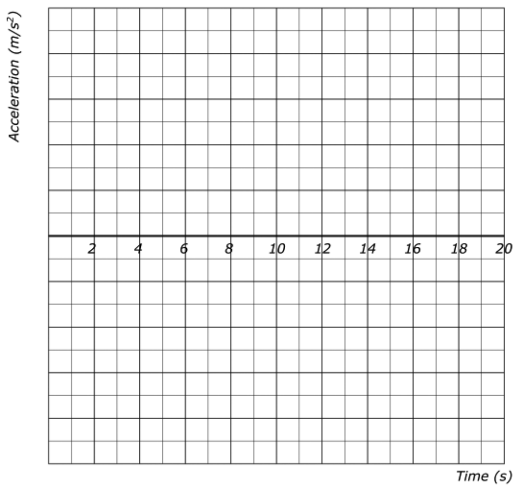
Scenario

A rocket fires its engines to launch straight up from rest with an upward acceleration of 5 m/s^2 *for* 10 *seconds. After this time, the engine shuts off and the rocket freely falls straight down back to Earth's surface.*

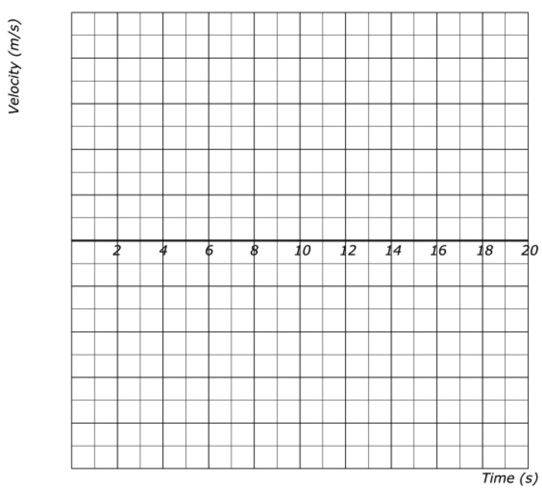


Using Representations

PART A: Draw a graph of the acceleration as a function of time from $t = 0$ seconds to $t = 20$ seconds.



PART B: Draw a graph of the velocity as a function of time from $t = 0$ seconds to $t = 20$ seconds.



Quantitative Analysis

PART C: Using the kinematics equation $y = y_0 + v_{y0}t + \frac{1}{2}a_y t^2$, a classmate writes out the following solution to find the time when the rocket lands back on Earth. Explain in one sentence, using terms such as *acceleration, velocity, position, constant, changin*g, and *zero*, why the solution below is incorrect.

$$y = y_0 + v_{y0}t + \tfrac{1}{2}a_y t^2$$

$$0 = 0 + \left(0\tfrac{m}{s}\right)t + \tfrac{1}{2}\left(5\tfrac{m}{s^2}\right)t^2$$

Argumentation

PART D: From your velocity vs. time graph in Part B, determine the time when the rocket reaches its maximum height.

Time for the rocket to reach its maximum height = ___________________

Explain how you determined your answer.

PART E: Make a claim about the numerical value of the rocket's maximum height.

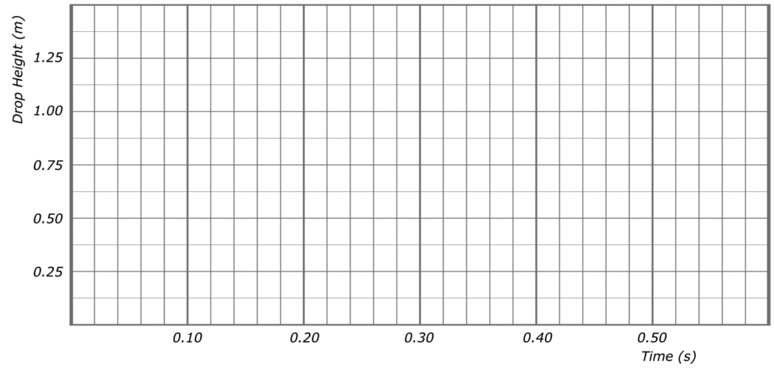
The rocket's maximum height is equal to ___________

Evidence: What physical feature of the velocity vs. time graph supports your claim?

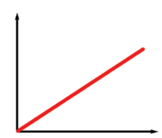
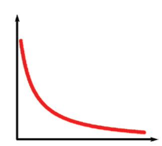
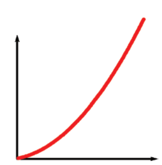
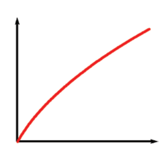
NAME ______________________________ DATE ______________

Scenario

Angela, Blake, and Carlos have been given a stopwatch, several large spheres, and a meterstick and have been asked to determine the acceleration due to gravity. They decide that they need to collect drop height and time to fall for the ball at several different heights to create a position vs. time graph. The averages of the collected data are shown in the data table below.



H *(m)*	***T*** *(s)*	
0	0	
0.50	0.32	
0.75	0.40	
1.0	0.46	
1.25	0.50	

Graph	***Relationship***
	As *x* increases, *y* increases proportionally. *y* is directly proportional to *x*.
	As *x* increases, *y* decreases. *y* is inversely proportional to *x*.
	*y* is proportional to the square of *x*.
	The square of *y* is proportional to *x*.

Quantitative Analysis

PART A: Graph the drop height as a function of fall time on the axis above.

PART B: Based on your graph and the table at the right, identify the correct relationship between the drop height and the time to fall to the ground.

Claim: The ____________________ is
(physical quantity)

____________________________ to the ____________________
(proportional / inversely proportional) (square / square root)

of ______________
(physical quantity)

PART C: The relationship between drop height and time to fall can be compared to the equation for a line, so that the students can create what is called a linearized graph. Fill in the third column in the data table with appropriate values and graph to create a linearized graph.

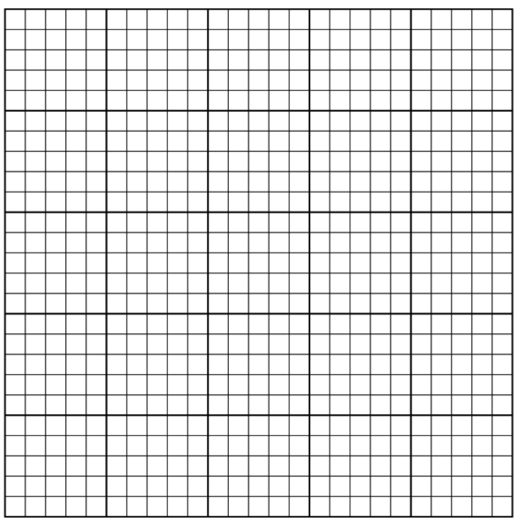
$H \propto t^2$

$y = mx + b$

PART D: What quantities should be plotted on a graph if the graph is to have a linear trend and the slope of the best-fit line is to be used to determine the acceleration due to gravity?

Using Representations

PART E: Plot the appropriate quantities stated in Part D on the graph below. Label the axes with quantities, a scale, and appropriate units. Draw a best-fit line.



Quantitative Analysis

PART F: Using the best-fit line, determine the acceleration due to gravity. (Hint: Carefully calculate the slope of the best-fit line and determine the relationship between the quantities you plotted and the acceleration due to gravity.)

Appendix D

ADVANCED PLACEMENT PHYSICS 1 TABLE OF INFORMATION

CONSTANTS AND CONVERSION FACTORS	
Universal gravitational constant, $G = 6.67\times10^{-11}\ \text{m}^3/(\text{kg}\cdot\text{s}^2) = 6.67\times10^{-11}\ \text{N}\cdot\text{m}^2/\text{kg}^2$	Acceleration due to gravity at Earth's surface, $g = 9.8\ \text{m/s}^2$
1 atmosphere of pressure, $1\ \text{atm} = 1.0\times10^5\ \text{N/m}^2 = 1.0\times10^5\ \text{Pa}$	Magnitude of the gravitational field strength at the Earth's surface, $g = 9.8\ \text{N/kg}$

PREFIXES		
Factor	Prefix	Symbol
10^{12}	tera	T
10^{9}	giga	G
10^{6}	mega	M
10^{3}	kilo	k
10^{-2}	centi	c
10^{-3}	milli	m
10^{-6}	micro	μ
10^{-9}	nano	n
10^{-12}	pico	p

UNIT SYMBOLS				
	hertz,	Hz	newton,	N
	joule,	J	pascal,	Pa
	kilogram,	kg	second,	s
	meter,	m	watt,	W

VALUES OF TRIGONOMETRIC FUNCTIONS FOR COMMON ANGLES							
θ	0°	30°	37°	45°	53°	60°	90°
$\sin\theta$	0	$1/2$	$3/5$	$\sqrt{2}/2$	$4/5$	$\sqrt{3}/2$	1
$\cos\theta$	1	$\sqrt{3}/2$	$4/5$	$\sqrt{2}/2$	$3/5$	$1/2$	0
$\tan\theta$	0	$\sqrt{3}/3$	$3/4$	1	$4/3$	$\sqrt{3}$	∞

The following conventions are used in this exam**:**

- The frame of reference of any problem is assumed to be inertial unless otherwise stated.
- Air resistance is assumed to be negligible unless otherwise stated.
- Springs and strings are assumed to be ideal unless otherwise stated.
- Fluids are assumed to be ideal, and pipes are assumed to be completely filled by fluid, unless otherwise stated.

GEOMETRY AND TRIGONOMETRY

Rectangle

$A = bh$

Triangle

$A = \frac{1}{2}bh$

Circle

$A = \pi r^2$

$C = 2\pi r$

$s = r\theta$

Rectangular Solid

$V = \ell wh$

Cylinder

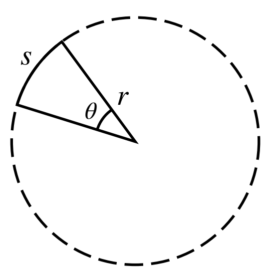
$V = \pi r^2 \ell$

$S = 2\pi r\ell + 2\pi r^2$

Sphere

$V = \frac{4}{3}\pi r^3$

$S = 4\pi r^2$



A = area
b = base
C = circumference
h = height
ℓ = length
r = radius
s = arc length
S = surface area
V = volume
w = width
θ = angle

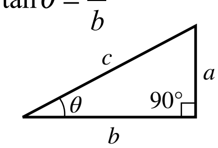
Right Triangle

$a^2 + b^2 = c^2$

$\sin\theta = \frac{a}{c}$

$\cos\theta = \frac{b}{c}$

$\tan\theta = \frac{a}{b}$



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MECHANICS AND FLUIDS

$v_x = v_{x0} + a_x t$

$x = x_0 + v_{x0} t + \frac{1}{2} a_x t^2$

$v_x^2 = v_{x0}^2 + 2a_x \left(x - x_0\right)$

$\vec{x}_{\text{cm}} = \frac{\sum m_i \vec{x}_i}{\sum m_i}$

$\vec{a}_{\text{sys}} = \frac{\sum \vec{F}}{m_{\text{sys}}} = \frac{\vec{F}_{\text{net}}}{m_{\text{sys}}}$

$\left|\vec{F}_g\right| = G\frac{m_1 m_2}{r^2}$

$\left|\vec{F}_f\right| \leq \left|\mu \vec{F}_n\right|$

$\vec{F}_s = -k\Delta\vec{x}$

$a_c = \frac{v^2}{r}$

$K = \frac{1}{2} m v^2$

$W = F_{\parallel} d = F d \cos\theta$

$\Delta K = \sum W_i = \sum F_{\parallel,i} d_i$

$\Delta U_s = \frac{1}{2} k (\Delta x)^2$

$U_G = -\frac{G m_1 m_2}{r}$

$\Delta U_g = m g \Delta y$

$P_{\text{avg}} = \frac{W}{\Delta t} = \frac{\Delta E}{\Delta t}$

$P_{\text{inst}} = F_{\parallel} v = F v \cos\theta$

$\vec{p} = m\vec{v}$

$\vec{F}_{\text{net}} = \frac{\Delta \vec{p}}{\Delta t} = m\frac{\Delta \vec{v}}{\Delta t} = m\vec{a}$

$\vec{J} = \vec{F}_{\text{avg}} \Delta t = \Delta \vec{p}$

$\vec{v}_{\text{cm}} = \frac{\sum \vec{p}_i}{\sum m_i} = \frac{\sum (m_i \vec{v}_i)}{\sum m_i}$

a = acceleration
d = distance
E = energy
F = force
J = impulse
k = spring constant
K = kinetic energy
m = mass
p = momentum
P = power
r = radius, distance, or position
t = time
U = potential energy
v = velocity or speed
W = work
x = position
y = height
θ = angle
μ = coefficient of friction

$\omega = \omega_0 + \alpha t$

$\theta = \theta_0 + \omega_0 t + \frac{1}{2}\alpha t^2$

$\omega^2 = \omega_0^2 + 2\alpha\left(\theta - \theta_0\right)$

$v = r\omega$

$a_T = r\alpha$

$\tau = r_{\perp} F = r F \sin\theta$

$I = \sum m_i r_i^2$

$I' = I_{\text{cm}} + M d^2$

$\alpha_{\text{sys}} = \frac{\Sigma\tau}{I_{\text{sys}}} = \frac{\tau_{\text{net}}}{I_{\text{sys}}}$

$K = \frac{1}{2} I \omega^2$

$W = \tau \Delta\theta$

$L = I\omega$

$L = r m v \sin\theta$

$\Delta L = \tau \Delta t$

$\Delta x_{\text{cm}} = r \Delta\theta$

$T = \frac{1}{f}$

$T_s = 2\pi\sqrt{\frac{m}{k}}$

$T_p = 2\pi\sqrt{\frac{\ell}{g}}$

$x = A\cos(2\pi f t)$

$x = A\sin(2\pi f t)$

$\rho = \frac{m}{V}$

$P = \frac{F_{\perp}}{A}$

$P = P_0 + \rho g h$

$P_{\text{gauge}} = \rho g h$

$F_b = \rho V g$

$A_1 v_1 = A_2 v_2$

$P_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = P_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$

a = acceleration
A = amplitude or area
d = distance
f = frequency
F = force
h = height
I = rotational inertia
k = spring constant
K = kinetic energy
ℓ = length
L = angular momentum
m = mass
M = mass
P = pressure
r = radius, distance, or position
t = time
T = period
v = velocity or speed
V = volume
W = work
x = position
y = vertical position
α = angular acceleration
θ = angle
ρ = density
τ = torque
ω = angular speed

Appendix E

Iona Prep
Course Syllabus

AP Physics I
2024-2025

Instructor: Mr. Michael J Cellini
Email: mcellini@ionaprep.org
Phone: 914-632-0714 x314
Extra Help Schedule: *M-F mornings 7:30-8:15 am*
M or W afternoons 2:50-3:30 pm
Location: RM 117
appointment only in person (Google meet subject to circumstances)

Course Description: The AP Physics 1 course will meet for 41 minutes every day. Lab work is integral to the understanding of the concepts in this course. The AP Physics 1 Course has been designed by the College Board as a course equivalent to the algebra-based college-level physics class. At the end of the course, students will take the AP Physics 1 Exam, which will test their knowledge of both the concepts taught in the classroom and their use of the correct formulas. The content for the course is based on five big ideas [CR2-11]:

o Big Idea 1 – Objects and systems have properties such as mass and charge. Systems may have internal structure.

o Big Idea 2 – Fields existing in space can be used to explain interactions.

o Big Idea 3 – The interactions of an object with other objects can be described by forces.

o Big Idea 4 – Interactions between systems can result in changes in those systems.

o Big Idea 5 – Changes that occur as a result of interactions are constrained by conservation laws.

Learning Goals: Have students work together to solve problems using concepts in physics. Understanding and making models to describe, explain, predict, design, and control physical phenomena. Utilize critical thinking skills to abstract information from problems, applying concepts and equations from lecture, and performing proper calculations to solve problems. Using real world examples to show how physics is applied everywhere. Doing all of this **with an emphasis on problem solving** will properly prepare for the AP Physics 1 exam. [CR12-19]

Student Practice: Throughout each unit, Topic Questions will be provided to help students check their understanding. The Topic Questions are especially useful for confirming understanding of difficult or foundational topics before moving on to new content or skills that build upon prior topics. Topic Questions can be assigned before, during, or after a lesson, and as in class work or homework. Students will get rationales for each Topic Question that will help them understand why an answer is correct or incorrect, and their results will reveal misunderstandings to help them target the content and skills needed for additional practice.

At the end of each unit or at key points within a unit, Personal Progress Checks will be provided in class or as homework assignments. Students will get a personal report with feedback on every topic, skill, and question that they can use to chart their progress, and their results will come with rationales that explain the solution to every question. One to two class periods are set aside to re-teach skills based on the results of the Personal Progress Checks.

Class Expectations: *Organization* is the key to success. Students are expected to read the assigned sections from the textbook prior to lecture for homework some nights. The textbook is meant to help students grasp the ideas that will be presented to them the following day. It is imperative for students to pay attention to the lecture, as it will present concepts, equations, and applications of the material covered in the textbook. Having a spiral notebook is the most useful (and only) thing students can use for note taking, as there will be many diagrams, equations, and problem-solving during lectures. Having a notebook will make it easy to write down your own ideas and questions. Classwork and homework will come from the textbook and or supplemental material, but exams and quizzes will use the AP test bank. Using questions and problems from old AP exams will condition the students to the type of understanding and thinking they will need for when they take the AP exam. In class exams will mimic AP exams. Laboratory procedures and the following lab report are meant for students to grasp a real-world application of topics covered in class. It allows them to solve problems within a real-world context. The AP exam does not ask questions about specific labs, rather general lab concepts. Therefore, we will do at least one lab for each unit, required by the course.

*On PlusPortals under Class Files, the students will find documents such as class PowerPoints, homework solutions, and test prep material.
*Students should regularly check PlusPortals for all other postings and links. As a class we can create a Google Classroom Site.

Class Materials:

Required Text

College Physics for the AP Physics 1 Course, Second Edition by Gay Stewart, Roger Freedman, Todd Ruskell, Philip Keston 2019 [CR1]

Materials

School Issued IPAD with a compatible digital pen/pencil
(Notebook/Lab notebook will be digitally created and saved in a folder on the IPAD)
Binder or folder for returned and current paperwork
Scientific calculator
Pencils and erasers only allowed (***no ink pens allowed in class***)
Ruler

Online access websites

PlusPortals
Google classroom
Pearson online textbook account
CK-12 website
TeacherMade
TurnItIn

Units Covered [CR2-11]**:**

1. Kinematics (Big Idea 3) [CR2]
    a. Vectors/Scalars
    b. One Dimensional Motion (including graphing position, velocity, and acceleration) c. Two Dimensional Motion
2. Dynamics (Big Ideas 1, 2, 3, and 4) [CR3]
    a. Newton's Laws of Motion and Forces
3. Circular Motion (Big Ideas 1, 2, 3, and 4) [CR4]
    a. Universal Law of Gravitation
4. Energy (Big Ideas 3, 4, and 5) [CR5]
    a. Work
    b. Energy
    c. Conservation of Energy
    d. Power
5. Momentum (Big Ideas 3, 4, and 5) [CR6]
    a. Impulse and Momentum
    b. The Law of Conservation of Momentum
6. Torque and Rotational Motion (Big Ideas 3, 4, and 5) [CR8]
    a. Rotational Kinematics
    b. Rotational Energy
    c. Torque and Rotational Dynamics
    d. Angular Momentum
    e. Conservation of Angular Momentum
7. Simple Harmonic Motion (Big Ideas 3 and 5) [CR7]
    a. Simple Pendulums
    b. Mass-Spring Oscillators

Homework: Students at Iona Prep are to be prepared for class each and every day. Homework will consist of reading, completing problem sets, reviewing lectures, and studying for the next day's topics. Even though homework will not be collected or graded on a continual basis, it is imperative for students to actively complete these assignments to the best of their ability and more importantly come in daily with questions from the previous night's work. This homework will be posted and announced daily. Students are allowed to receive help and work together in these assignments

In-Class Assignments: Students will complete 2-3 assignments in class throughout the week that will be submitted and graded. These assignments will be based on the daily homework assigned each day. These assignments will not be posted or announced, as the student will be expected to come in each day prepared to complete. Students will work individually on these assignments, unless told otherwise by the teacher.

Weekly Real World Application: Students will solve a real world problem. This problem will be assigned at the beginning of the school week and due at the completion of the week. The problem will address real world application of topics discussed throughout the week.

PBL Activities: Certain lessons throughout the year will involve the use of PBL learning and practice activities that will focus on student engagement, working in teams, and enhancing understanding of course material. Students are responsible to complete activities in the allotted time and be actively engaged in group discussions. These PBL activities will be heavily weighted towards student participation in class. Any topics covered during these lessons will be assessed through traditional means of multiple choice and short answer questions.

Assessments: Formative unit assessments will take place on the completion of each unit. These exams will often take two school periods to complete. The format of these assessments will be multiple choice and free response questions. The focus of these assessments is to show that students are able to review various topics and retain the information from the previous weeks. Students will demonstrate a mastery of the skills they acquired throughout the unit.

All test and due dates will be posted in advance on PlusPortals.

Make-Up Exams: It is good practice to return and review graded tests as soon as possible after the test has been administered. For that reason, if a student is absent on a day when a test is given, he will normally be expected to take the missed test on the day he returns to school. That way, after all tests have been administered, they may be graded, returned and reviewed. Exam make-ups will be given in the mornings starting at 7:30 AM on the day of the student's return and will be taken in the Physics Room 117 in front of the teacher. Students will be expected to be prepared for exams. No exceptions will be made.

Laboratory Activities: Students will spend twenty five percent (25%) of the course engaged in hands-on laboratory work. Labs may take several in-class days to finish, and students may have to do work outside of class as well. Students are expected to keep a lab notebook where they will maintain a record of their laboratory work. Lab reports will consist of the following components, and can be adjusted:

-*Title*
-*Objective/Problem*
-*Design (if applicable)*: If the lab has no set procedure, what is to be done? Why are you doing it this way?
-*Data*: All data gathered in the lab will go here
-*Calculations/Graphs*: Calculations are done here. Any graphs that need to be made go here.
-*Conclusion*: Data analysis occurs here, and a statement can be made about what was learned in the lab. Error analysis also occurs here. Evaluation of the lab occurs here as well.

Every major unit will have an inquiry-based lab, and inquiry-based labs will make up no less than half of the laboratory work. Collectively, laboratory work will engage students in all science practices.

Performance: Each student will begin each quarter with a 100% performance grade. This grade will be dependent on the student's performance in class, focusing on respect of his peers and the teacher, following directions, adhering to proper school policy, arriving on time for class, and completing all assignments on time. Every time there is an infraction points will be deducted from this score.

Grade Weighting: All grades will be based on a total points distribution for all assignments, projects, labs, quizzes, and exams. Throughout the course we will strive to accumulate 500-600 points in total for each quarter, depending on the amount of graded work completed. As such, students should expect exam grades to contribute to roughly 40% of their total average for each quarter, while the remaining 60% will focus on quizzes, projects, labs, and participation.

Outside the Classroom Lab Experience with Real World Physics Problem: Students will be required to participate in at least one out of the classroom lab experience. This will take form as a project which specifics will vary depending on the topic. The goal of this exercise is to have students engage in their own study of a problem they have seen in the real world. Then applying their skills and knowledge from class, they will present their findings and solution to their peers, where they will defend it. [CR12-21]

Rubric: Generally, assignments (homework, labs and projects) are graded with three factors: completeness, accuracy, and neatness. An assignment may have a specific, individualized rubric.

	Beginning 1	Developing 2	Accomplished 3	Exemplary 4
Completeness	Most tasks were not completed	Less than 50% of lab tasks / write up completed	Most of tasks completed	All tasks completed, no omissions
Accuracy	Presents illogical explanation of findings	Presents an illogical explanation for findings and addresses few questions	Presents a logical explanation for findings and accurately addresses some questions	Presents a logical explanation for findings and accurately addresses most questions
Neatness	Illegible writing, loose items	Legible writing / typed, many typos	Legible writing / typed, few typos, charts and pictures provided	Extreme care taken. All elements correctly placed and well thought out

Cheating and Plagiarism: Plagiarism is the "use or close imitation of the language and thoughts of another author and the representation of them as one's own original work." Don't do it. Work deemed as plagiarism will receive zero credit.
The full policy is located here:
https://docs.google.com/document/d/112hksR9xG77x5FSEG0g0gMC7pLTvmynhEnsR1I1aLkg/edit?usp=sharing

Attendance & Late Work: In order to be successful in this class regular attendance is mandatory. Missing class time makes it much more difficult for the student to keep up with the material. It is the responsibility and expectation of the student to check the PlusPortals/Google Classroom for assignments and due dates and to complete assignments on time. Normally, no credit will be allowed for late assignments. In the case of an absence, work is due the day the student returns to school. It is not the responsibility of the teacher to reteach any missed lessons. You will be expected to complete assignments, get notes from classmates, and learn the material on your own before seeking teacher assistance. The teacher will address misconceptions but WILL NOT reteach any missed lessons.

**** Any student going on a planned trip (academic, athletic, service, etc.) must be up-to-date on all assignments prior to departure. Furthermore, all assignments and tests must be made up within a week of returning. Not doing so may result in receiving reduced credit or no credit for late assignments. ****

Tardiness: Students are expected to arrive on time for every class. Arriving late will require documentation from administration on lateness/detention slip. Any students arriving late continuously will be sent to the front office or Dean of Discipline. Detention slips WILL BE handed out for being late. NO EXCEPTIONS!

Use of Electronic Devices:
Students will only be able to use their electronic devices (cell phones/IPADS) after receiving explicit permission from the teacher. LAPTOPS ARE NOT PERMITTED IN CLASS!

Use of cell phones is not permitted and students will be required to place phones in the electronics bin at the start of class and retrieve their devices at the end of class. Any use of cell phones will result in confiscation for the remainder of the day. Students can pick up devices at the main office. Repeat offenses will result in administrative discipline and/or removal from class.

Only school issued Ipads are allowed to be used in class. Students are aware the teacher is able to disable any APPS/websites not needed for class. If any student is caught using Ipads for prohibited behavior he will be sent to the Dean of Discipline for

Uniform: Students are required to wear the approved Iona Prep uniform and ID cards for the entirety of class. Any removal of clothing (blazers) will be approved on a case by case basis by the teacher.

Distance Learning: See Parent-Student Handbook for the Iona Prep Distance Learning Code of Conduct

I look forward to sharing a successful year with you. If there are any questions or concerns, please feel free to contact me at school through my email.

Student Signature: ____

Parent/Guardian Signature: _______________________________________

Laboratory Activities:

Name	Open Inquiry or Guided Inquiry?	Short Description	Science Practices
#1 Speed Lab	Y	Students will design an experiment to determine the range of speeds of a variable speed cart.	2.1, 2.2, 4.1, 4.2, 4.3
Three Cars Racing Simulation	N	A computer simulation of three cars with different accelerations racing.	1.4, 2.2, 4.3, 6.1
#2 Rocket Lab	Y	Students will design an experiment to determine the initial velocity of an air-powered rocket.	1.2, 1.4, 2.1, 2.2, 4.1, 4.2, 4.3
Marble in Cup Lab	N	Students will determine where a paper cup needs to be placed on the floor so that a marble rolled off of the edge of a table will land in it.	1.4, 2.1, 2.2, 2.3, 4.3
#3 Projectile Motion Challenges	Y	Using a projectile launcher, students will be given a series of challenges such as placing a ring stand at the maximum height, or placing a cup at the point where the marble will land.	1.4, 2.1, 2.2, 4.1, 4.2, 4.3
#4 Newton's 2nd Law Lab	Y	What is the relationship between the mass of a system and the acceleration of the system?	1.1, 1.4, 2.1, 2.2, 3.3, 4.1, 4.2, 4.3, 4.4, 5.1, 6.1, 6.2, 6.4
Forces on a Crate Simulation	N	Using a simulation, analyze the motion of a crate. Students can vary the force on the crate, the direction of that force, the initial velocity of the crate, and the coefficient of kinetic friction.	1.1, 1.4, 2.2, 4.3, 6.1
Jupiter's Moons	N	Students will do research on Jupiter and four of its moons. Based on this research, students will mathematically come up with the mass of Jupiter. They will compare this information to the accepted value.	1.1, 1.4, 2.1, 2.2, 3.3, 4.1, 4.2, 4.3, 4.4, 5.1, 6.1, 6.2, 6.4, 7.1
#5 Pendulum Lab	Y	What factor(s) control the period of a simple pendulum?	1.1, 1.4, 2.1, 2.2, 3.3, 4.1, 4.2, 4.3, 4.4, 5.1, 6.1, 6.2, 6.4
#6 Mass-Spring Oscillator Lab	Y	Students must determine both the spring constant k of a spring and the mass of three unknown masses. Students must also investigate the conservation of mechanical energy of the system. Materials given: spring with	1.1, 1.4, 2.1, 2.2, 3.3, 4.1, 4.2, 4.3, 4.4, 5.1,6.1, 6.2, 6.4

		unknown spring constant, known masses, unknown masses.	
#8 Conservation of Linear Momentum Lab	Y	Using a track and collision carts students will observe seven different collisions and make conclusions about momentum conservation in real life situations.	1.1, 1.4, 2.1, 2.2, 3.3, 4.1, 4.2, 4.3, 4.4, 5.1, 6.1, 6.2, 6.4, 7.2
A Two Car Collision Simulation	N	Students will observe a simulation of two identical cars crashing. The elasticity of the collision can be varied.	1.1, 1.4, 2.2, 4.3, 6.1
#8 Introductory Circular Motion Lab	Y	When velocity is kept constant, what is the relationship between the radius of circular motion and the period of circular motion? The speed? The acceleration?	1.1, 1.4, 2.1, 2.2, 3.3, 4.1, 4.2, 4.3, 4.4, 5.1, 6.1, 6.2, 6.4
#9 Centripetal Force Lab	Y	Using a spinning rubber stopper to lift masses, students will determine the relationship between the acceleration of the stopper and the centripetal force.	1.1, 1.4, 2.1, 2.2, 3.3, 4.1, 4.2, 4.3, 4.4, 5.1, 6.1, 6.2, 6.4
#10 Conservation of Angular Momentum Lab	Y	What is the relationship between the moment of inertia of a system and the angular momentum of a system?	1.1, 1.4, 2.1, 2.2, 3.3, 4.1, 4.2, 4.3, 4.4, 5.1, 6.1, 6.2, 6.4
Torque Simulation	N	Students will use a computer simulation to study rotational equilibrium.	1.1, 1.4, 2.2, 4.3, 6.1