Physics 55 Syllabus and Course Description

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1.1 General Course Description

Instructor: Robert G. Brown Room 260
Email address: rgb at phy.duke.edu Cell Phone: 919-280-8443
Course Web page address: http://www.phy.duke.edu/∼rgb/Class/phy55.php
Text: *Universe*, by Freedman, Geller and Kaufmann, 9th ed.
ISBN-13: **978-1-4292-3153-4**

Physics 55 is *Astronomy* – a comprehensive review of the science and observational methodology of deciphering the visible Universe. It begins with a review of history and philosophy (astronomy played a key role in developing a rational and scientific worldview over several thousand years of civilization) leading to the scientific method as a valid way of ascertaining probable truth of assertions about the world. It continues with a review of what we know and *how* we know key astronomical facts about the Earth, the Earth-moon system, the Sun, the Earth-Sun system, the planets (and other interesting near-space objects) and the Solar System, the local group of stars (ones that can be located using parallax), the Milky Way galaxy, the local group of galaxies (ones within a few million light years) and the deep space observations of distant galaxies and the microwave background that are evidence of the Big Bang.

At all points *both* learning the facts *and* understanding why we believe them to be facts is emphasized. Students will not need any particular complicated mathematics to excel in the course, but will need to be able to understand some relatively simple geometry and trigonometry and to be able to visualize things using geometric drawings and compute things with simple algebra and arithmetic.

A final point of emphasis in the course is learning how to use modern instrumentation – personal computers and telescopes – to observe a wide range of objects of interest in the night sky and to learn to "navigate" the celestial heavens using star charts and/or planetarium software. Amateur astronomy is a rewarding hobby that can last a lifetime and that isn't terribly expensive (a very good telescope indeed can cost anywhere from $500 to $1500). Amateur astronomers over the years have made many significant contributions to science, including the discovery of asteroids, moons, comets, and supernovas. The big observatories do their best to watch the sky, but – there is a lot of sky! They also spend *most* of their time watching one small part of it. Amateurs watch different parts of the whole thing as their interests dictate, and not infrequently are the first to see something "interesting" – and get their name on it!

1.2 Useful Links and Resources

The class website will be here:

http://www.phy.duke.edu/∼rgb/Class/phy55.php

This will provide links to this document (the class syllabus and ruleset), the homework, and anything else you might need to look at as the course proceeds.

A *free* planetarium software tool for all platforms can be downloaded here:

http://www.stellarium.org/

This tool should be *very useful* to you as you try to visualize the sky or locate specific objects of interest. I urge you to download it and try it right away; next week assignments may involve using it.

I have a few CD's containing *Starry Nights* software, a very similar tool that is free to purchasers of the *Universe* textbook. Students are free to install this on any of their systems from my copies as long as they return the originals.

The regular semester class in Astronomy has a lovely set of online lecture notes in the form of power point slides. Our summer course will not follow exactly the same sequence as the regular class (we have to compress things a bit) but you may still find the online slides very useful as a summary and explanation of some of the things in the book. They are here:

http://www.cgtp.duke.edu/∼plesser/phy55-spring10/lectures.htm

There may be times where you want to look over some results from introductory physics in some sort of a physics textbook (although most of the time my lectures will be self-contained). To keep you from having to rely on an outside text, you can consider looking here at my online lecture notes/text.

http://www.phy.duke.edu/∼rgb/Class/intro_physics_1.php
http://www.phy.duke.edu/∼rgb/Class/intro_physics_2.php

1.3 Observatory and Observation

One important (required!) part of the course (as noted above) will be observation and learning to use a modern "amateur" grade telescope in conjunction with star charts or planetarium software. Duke has its own observatory area, located in Duke Forest not too far from campus. This is some distance away from the city lights, but still quite low and near to the city and hence subject to haze and some degree of light pollution from Durham. It is, however, far better than the old observing facility on the roof of the physics building surrounded by campus lights!

A map of the route from campus to the observatory can be found here, or you can follow these verbal instructions:

> The observatory is located in the Duke Forest, on Cornwallis Rd, about one mile west of Kerley. From the Duke Physics building, drive down Science Drive until it terminates on NC 751 (Cameron). Turn right. Proceed down the hill, under US 15-501, and down the hill again to a traffic circle. Go 3/4 of the way around the circle and turn right onto Erwin Road (towards Chapel Hill). Proceed a half mile or so over a bridge and up a hill and turn right (west) on Cornwallis at the light and proceed a bit more than two miles (past Kerley Road, then start looking on the left). Access to the observatory is through a Duke Forest gate on the left hand side of the road. (The gate is usually locked unless observatory is open). The gravel road through the gate forks soon. Follow the road to the right around a large shed and park in front of the shed. Turn off car headlights as soon as you have stopped! Walk down the hill to your left (away from Cornwallis) to the observatory site, about 150ft.

> A radio tower with a flashing red light is also located off of the left side of Cornwallis just *past* the correct entrance. If you get to the radio tower, you have gone too far – turn around and come back and look on the right as you come past the tower.

The telescopes at the site are located in a locked shed and have to be taken out and assembled on fixed stands, and then taken down at the end of the day. Students will be learning to do this themselves – one important goal of the course is to teach you enough that you will be able one day to buy your own telescope and assemble/disassemble it as needed and use it to enjoy amateur astronomy for the rest of your life!

Before your first trip to the observatory, please download and save/print your own copy of the assembly instructions for the telescopes:

http://www.cgtp.duke.edu/∼plesser/observatory/LX200GPS%20Assembly.htm

Bring this copy with you to the viewing, along with a tiny flashlight if you have one. Setting up will usually happen while there is still daylight, but taking down will be done late, when it is quite dark.

Visitors Are Welcome! If your roommate or some friends want to come along, that's fine (especially if you have your own transportation). Please let me know, however, if you plan to bring somebody just so I can keep a running total of how many people we are likely to have in my mind.

Bringing beverages is permitted (it can be hot and viewing sessions can last for four or five hours on a really good night) but plan to carry out your trash. I personally don't care if the beverages are alcoholic as long as students both comply with NC law and Duke policy regarding them *and* comply with my own standards of polite behavior and moderation while handling expensive pieces of equipment. Remember that you will have to drive back to campus, as well, and that the roads to and from the observatory are full of deer and other hazards at night! Gentle, sober driving and good reflexes are definitely called for...

1.3.1 Observation Hazards: Mosquitos, Ticks, Chiggers

North Carolina in the summer has mosquitos, and the observatory is basically in a mowed patch of a grassy field in the middle of the woods in Duke Forest. Deer and other animals move through the fields all day and night (we may well see some), carrying their natural parasites. The unmowed grass on all sides therefore contains a variety of pests including ticks and chiggers (and should generally be avoided). Please wear suitably protective clothing and/or spray exposed skin with insect repellent to minimize your risks of an annoying and possibly dangerous bite. I'll try to bring repellent with me whenever we have a session in case you have a hard time finding it.

Note well: ticks in North Carolina carry a significant health risk. Both *Lyme Disease* (from the small deer ticks) and *Rocky Mountain Spotted Fever* (from the larger dog ticks or lone star ticks) are moderately prevalent in North Carolina, and RMSF can be (and is, for one or two people a year including a UNC undergrad a few years ago) fatal if left undiagnosed and untreated until it is too late!

Although the risk of contracting either one from a bite is small (essentially zero unless the tick has been attached for around a full day) it is *always* wise to note the day you pull off any attached tick, and be sure to report it to your physician if you start to feel flu-ey – muscle aches and fever, with or without any "spotting" of your skin – around a week later.

Chiggers are tiny bugs that are naturally parasitic to birds. They begin life as vegetarians living on e.g. blades of grass, and we are not their natural targets. Although they are not actively dangerous (as far as I know), chigger bites (like tick bites) can itch for weeks or even months afterwards due to a localized allergic reaction to proteins in the chigger or tick's mouth fluids. Fortunately, chiggers do not generally attach or bite right away, and a shower/inspection after any exposure is usually enough to dislodge any unwelcome visitors before they bite.

This information isn't intended to make you scared to go to the observatory at all (you can just as easily get a tick from a walk through the Duke Gardens) – just to use some sense and not go to a session wearing shorts and sandals without any insect repellent, then go wandering off into the grass, and then going home and straight to bed. RMSF is easily treated if caught early (I had it myself a couple of years ago). If you shower and check yourself for ticks upon return from any trip into Duke Forest during the warm months, you should be fine.

1.3.2 Transportation

Transportation to a remote observatory off campus is always an issue. If you need a ride, please let me know. I have a car that is large enough that I could take as many as seven or eight students with me (in a pinch) from campus to the obaservatory, or you may be able to hitch a ride with other students in the class. Remember, my cell phone is 280-8443.

1.4 Wikilinks

Wikipedia is well on its way to becoming the "Universal Textbook", with link chapters that span almost any subject especially in physics, mathematics, philosophy – things people care about.

I would suggest that at you own convenience you take "wikiromps" starting at any of the following links and following article links as it suits you until you have a pretty good understanding of the history and basic concept associated with the following ideas or laws. We'll then work extensively in class and our observation sessions to turn that initial understanding into deep operational knowledge.

This list will expand as we encounter new concepts during the semester, although (as you'll note) you may well get to them quite early on your wikiromps as links will carry you quickly from "intro" level articles to graduate school level articles. Read and become familiar at your own pace, but don't hold back on following links to more difficult or advanced articles.

- Wikipedia: http://www.wikipedia.org/wiki/Astronomy
- Wikipedia: http://www.wikipedia.org/wiki/Universe
- Wikipedia: http://www.wikipedia.org/wiki/Cosmology
- Wikipedia: http://www.wikipedia.org/wiki/Earth

- Wikipedia: http://www.wikipedia.org/wiki/Telescope
- Wikipedia: http://www.wikipedia.org/wiki/Observatory
- Wikipedia: http://www.wikipedia.org/wiki/Parallax
- Wikipedia: http://www.wikipedia.org/wiki/Parsec
- Wikipedia: http://www.wikipedia.org/wiki/Light-year
- Wikipedia: http://www.wikipedia.org/wiki/Moon
- Wikipedia: http://www.wikipedia.org/wiki/Sun
- Wikipedia: http://www.wikipedia.org/wiki/Star
- Wikipedia: http://www.wikipedia.org/wiki/Nebula
- Wikipedia: http://www.wikipedia.org/wiki/Star Cluster
- Wikipedia: http://www.wikipedia.org/wiki/Planet
- Wikipedia: http://www.wikipedia.org/wiki/Galaxy
- Wikipedia: http://www.wikipedia.org/wiki/Comet
- Wikipedia: http://www.wikipedia.org/wiki/Asteroid
- Wikipedia: http://www.wikipedia.org/wiki/Meteoroid
- Wikipedia: http://www.wikipedia.org/wiki/Meteorite
- Wikipedia: http://www.wikipedia.org/wiki/Oort Cloud
- Wikipedia: http://www.wikipedia.org/wiki/Kuiper Belt
- Wikipedia: http://www.wikipedia.org/wiki/Quasar
- Wikipedia: http://www.wikipedia.org/wiki/Andromeda Galaxy
- Wikipedia: http://www.wikipedia.org/wiki/List of Messier Objects
- Wikipedia: http://www.wikipedia.org/wiki/Celestial Coordinate System
- Wikipedia: http://www.wikipedia.org/wiki/Right Ascension

- Wikipedia: http://www.wikipedia.org/wiki/Declination
- Wikipedia: http://www.wikipedia.org/wiki/Sidereal Time
- Wikipedia: http://www.wikipedia.org/wiki/Meridean
- Wikipedia: http://www.wikipedia.org/wiki/Ecliptic
- Wikipedia: http://www.wikipedia.org/wiki/Orbit
- Wikipedia: http://www.wikipedia.org/wiki/Kepler's Laws of Planetary Motion
- Wikipedia: http://www.wikipedia.org/wiki/Black Hole
- Wikipedia: http://www.wikipedia.org/wiki/Neutron Star
- Wikipedia: http://www.wikipedia.org/wiki/Right Ascension
- Wikipedia: http://www.wikipedia.org/wiki/Stellar Classification
- Wikipedia: http://www.wikipedia.org/wiki/Hertzsprung-Russell diagram
- Wikipedia: http://www.wikipedia.org/wiki/Cepheid Variable
- Wikipedia: http://www.wikipedia.org/wiki/Age of the Universe
- Wikipedia: http://www.wikipedia.org/wiki/Big Bang
- Wikipedia: http://www.wikipedia.org/wiki/Cosmic Microwave Background
- Wikipedia: http://www.wikipedia.org/wiki/Dark Matter
- Wikipedia: http://www.wikipedia.org/wiki/Dark Energy
- Wikipedia: http://www.wikipedia.org/wiki/Radiometric Dating
- Wikipedia: http://www.wikipedia.org/wiki/Astrophysics

1.5 Detailed Course Description

The course will consist of both lecture (with lots of discussion – I'd like to run a summer course very nearly "seminar style" as we *can* because of the small class size – and *required* viewing sessions. Viewing, unfortunately, will have to depend on the weather – some nights will be crisp, cool, clear, and moonless (ideal for telescope viewing, in other words) and others will be hazy, or raining, or the moon will be out and washing out all of the stars.

The *disadvantage* of summer courses is that we have no control over the moon and the weather, and so we'll have to take our viewing as we can get it in the six week stretch of the course. For that reason we will have "come as you are" observation sessions whenever the conditions are particularly good, and may even try to schedule a "field trip" to e.g. the Blue Ridge Parkway for an overnight viewing session far from the city lights and up relatively high, where the Milky Way can be better appreciated. I will try to give you adequate notice of nights that conditions will (probably) be good when I can, but sometimes the weather forecast will become favorable only on the day of viewing. We have only *one stretch where the moon will be completely absent* over the six week stretch (the next dark of the moon is June 12) so try to keep the stretch from last quarter through the new moon free in the evenings.

Observing is part of the *fun* of the course, so hopefully this will be no real burden. As noted above, you are also welcome to invite your friends to come along and view with us as long as we have room and time on the scopes to share (and as long as you let me know that you are bringing them so I can keep track of this).

After every observation session you will need to prepare a short report on what you viewed, including a hand-drawn star map of the night sky as you observed it on the night in question at some particular time. By comparing these maps at different times on the same night and at the same time on different nights over the course of the session, you can see first hand the apparent motion of the stars that leads us to understand the motion of the earth!

In this course we will cover the following basic topics (and answer some of the following basic questions):

- Science and Worldviews. What is "science" and how do we use it to understand the world around us? In particular, why should we usually believe *more* in the current scientific worldview than, say, in the worldview presented by the mythology of your choice? Why are numbers important? Why is evidence important? Why is consistency important?

- Simple Observational Astronomy. When we look up at the sky with the naked eye, what do we see? How can we systematize our observations and invent worldviews to explain them? What were the worldviews of ancient civilizations that attempted to explain what *they* saw?

- The Telescope. How do telescopes work? How does what one sees looking up at the sky with a telescope differ from what one can see with the naked eye? How do the things a telescope reveals force one to revise or reject some of the worldviews of ancient civilizations and their associated mythologies?

- Navigating the Sky. What coordinate system do we use to locate celestial objects (what are "right ascension" and "declination". How can we visualize where the earth is, how it moves, and how *everything else* moves relative to it? How can we find particular objects of interest in the night sky to look at them with either our naked eyes or a telescope[1]?

- The Earth. How the Earth rotates, revolves, is tipped, precesses, and is basically a cork storm-tossed by the gravitational fields of the *big* objects in the solar system. Also how this affects our ability to navigate and direct our telescopes.

- The Sun. All sorts of things about the Sun: What it appears to be made of, and how we know. How big it is. How massive it is. How much light (and other energy) it produces. How far away it is.

- The Planets and Solar System. How the whole solar system is put together. A tour of the planets in order, a tour of the moons of the planets, and a discussion of the other objects in our solar system: the

[1] This part of the course will involve the use of software that permits you to virtually navigate the heavens (and learn quickly what and how to punch coordinates into a telescope to find it for yourself). A major point will be to educate you to where you can be an amateur astronomer and have fun with a good telescope for the rest of your life!

asteroids, the comets, the oort cloud, meteoroids and meteorites, killer asteroids, and much more.

- Stars in Our Galaxy. How can we tell how far away they are (and thus turn our observations of their directions into a 3-D map!)? What is stellar classification and how does it work? What is the Hertzsprung-Russell diagram and how is it important in determining distances? What are Cepheid Variables and how are they useful in determining distances? How does parallax work? What's a parsec vs a light-year? How can we tell how fast a distant star is moving, and in what direction? How are stars formed? How do stars die?

- Galaxies. How many are there? What kinds are there? How far away are they? How do we know?

- The Big Bang. What is the evidence for the Big Bang? What are the ratios of the abundances of the elements observed in just about everything? What is the cosmic microwave background? How large is the visible Universe? How old is the visible Universe? What interesting things went on in the very early moments of this cycle of the Universe? What are dark matter and dark energy and why do we suspect that they are there?

- Miscellaneous Other Stuff. What are nebulas, neutron stars, black holes, quasars, double stars, variable stars, and many other "interesting" things observable in the night sky?

- Putting it All Together. The modern worldview and its cosmology. Why it is the *best* thing to believe – so far.

In order to learn something as interesting (but complex!) as astronomy, you have to invest time in study outside of class, especially on a summer schedule where there is less time for reflection. To help facilitate this, there will be a mixed bag of homework: both readings and some problems (although I expect to assign fewer problems than the regular course assigns given the time constraints).

I expect all students to *come to class*, to *do the assigned problems* and to *keep up with the reading.* I won't take attendance per se in class, but if you are routinely absent in a seminar style class it will be pretty obvious and I'll eventually start knocking down your grade.

The grading of the course will be (**approximately!**):

25% Homework

25% Observation and participation

25% Quizzes and exams

25% Final

As a starting point, you should assume something like:

$< 50\%$ F

$< 60\%$ D

$< 75\%$ C

$< 90\%$ B

$\geq 90\%$ A

This scheme should make it pretty easy to *pass* the course – do your homework, come to class and participate in the discussion in a way that shows that you've done the reading, participate in the viewing sessions and you will get at least a D even if you get a *zero* on all of the quizzes, exams, and final (which of course will never happen). To do *well*, of course, you'll have to do at least decently on the quizzes, exams, and final – but that should be easy enough if you've done your homework and reading and so on.

Note well that I reserve the right to tweak this scheme as needed *to your advantage* if the averages are unusually low, and that while most of your grade is objective, things like participation are at least partly subjective. I will try to provide feedback in a timely way if you are irritating me by not coming to class or coming to class but not having done any reading before it affects your grade, but ultimately showing up is your responsibility.

1.6 The Rules

- You **may** collaborate with your classmates in any permutation on the **homework**. In fact, I *encourage* you to work in groups, as you will probably all learn more that way. However, you must **each** write up *all* the solutions even if they are all the same within a group. Writing them up provides learning reinforcement.

- You **may** ask more advanced students, former students, me, other faculty, personal friends, or your household pets for help or tutoring on particular homework problems, as long as no worked–out solutions to the assigned problems are present when you work with them. Again, if you work in groups I *encourage* you to take turns teaching each other how to work through to the solutions to the problems you encounter, as teaching is an excellent way (perhaps the best way) to learn.

- You *may* use the library, textbook, and all available non–human resources on the web or elsewhere to help solve the homework problems, provided that you **understand it afterwards** (which is the primary goal), **cite your source** (if you have one), and provided that you do **not** use any resource labelled as "solutions to problems from Freedman et. al." – that is, for our specific textbook.

- Quizzes and Exams: All quiz and exam problems are to be worked out alone. Calculators may be used but the storing of formulae or other crutches in calculator memory or firmware or accessing the web in the middle of an exam to look up an answer is *obviously* strictly prohibited. Looking at or copying other students' work is equally obviously not permitted, and *will be severely penalized if discovered*. I *assume* that all my students are honorable persons and will play the game honestly – do not damage your own honor and spirit by behaving dishonorably in my class.

  Remember, I don't like grading you any more than you like being graded, and ultimately your *grade in this class does not matter*, at least no where nearly as much as you might think it does. What *does* matter is how much you *learn* – if you are getting a poor grade, it most likely reflects a failure to give the course the attention and effort it deserves and requires in order to properly facilitate that learning. Don't try to cheat your way to an empty and meaningless grade – come talk to me and we'll see if we can't repair your learning methodology to *earn* you a better one!

1.7 Personal Availability and Methods of Contact

I will usually be available for questions on any given day for an indefinite period following class (usually 1-2 hours, but I'm happy to make "office hours" extend over most of the afternoon if that is necessary). We'll schedule homework in such a way that you have at least one day to ask me questions or for help on any homework problems you are having difficulty with before you actually have to hand it in.

You can always contact me via email at rgb at phy dot duke dot edu, and usually I will get back to you in a matter of seconds to hours. If something is urgent, feel free to call my on my cell phone number: 919-280-8443. However, note well that this *is* my cell and will interrupt whatever I'm doing at the time, so please don't totally abuse it in the evenings or at night when we're not having a viewing. You can always send me a text message asking for a contact or leave a voicemail message if I don't pick up right away.

2 How to Do Your Homework Effectively

By now in your academic career it should be very apparent just where homework exists in the grand scheme of (learning) things. Ideally, you attend a class where a warm and attentive professor clearly explains some abstruse concept and a whole raft of facts in some moderately interactive way. Alas, there are *too many* facts to fit in short term/immediate memory and *too little time* to move most of them through into long term/working memory before finishing with one and moving on to the next one. As a consequence, by the end of lecture you've already *forgotten* many if not most of the facts, but if you were paying attention, asked questions as needed, and really cared about learning the material you *would* remember a handful of the most important ones, the ones that made your brief understanding of the material hang (for a brief shining moment) together.

Studies show that you are only likely to retain anywhere from 5% to 30% of what you are shown in lecture. Clearly this *is not enough* to make the information conceptually useful, to *learn* it. In order to actually learn, you must *stop* being a passive recipient of facts. You must *actively* develop your understanding, by means of *discussing* the material and kicking it around with others, by *using* the material in some way, by *teaching* the material to peers as you come to understand it.

Medical schools have long been aware of this. In the year 1907, medical schools had two years of coursework to prepare a student to be a physician. In the year 2007, they are *still* two years of coursework – but the amount of science and medicine that is taught in those two years has *exploded*. They have developed the following mantra to help their students understand the only way the process can still work:

- See one. (E.g. a procedure)
- Do one. (with a mentor standing by)
- Teach one. (still with a mentor, but a more advanced one still)

That's it! We will use our own version of this same process in this course. Lecture (seeing it done) is important – it sets the stage for the learning, but by itself it teaches little. Homework (doing it yourself) is far more important.

This is when you *begin* to really learn. Recitation (where you teach each other where you have learned) is where you solidify this learning by articulating it, working with the concepts in your mind at a high level to do so.

To help facilitate this process, associated with lecture your professor gave you an *assignment*. Amazingly enough, its purpose is not to torment you or to be the basis of your grade (although it may well do both). It is to give you some concrete stuff to *do* while thinking about the material to be learned, while discussing the material to be learned, while using the material to be learned to accomplish specific goals, while teaching some of what you figure out to others who are sharing this whole experience while being taught by them in turn.

In other words, to learn you must *do your homework*, ideally at least partly in a *group* setting. The only question is: *how* should you do it to both finish learning all that stuff you sort-of-got in lecture and to re-attain the moment(s) of clarity that you then experienced, until eventually it becomes a permanent characteristic of your awareness and you *know* and *fully understand* it all on your own?

There are two general steps that need to be *iterated* to finish learning anything at all. They are a lot of work. In fact, they are far *more* work than (passively) attending lecture, and are *more important* than attending lecture. You can learn the material with these steps without *ever* attending lecture, as long as you have access to what you need to learn in some media or human form. You in all probability will *never* learn it, lecture or not, without making a few passes through these steps. They are:

1. Review the whole (typically textbooks and/or notes)

2. Work on the parts (do homework, use it for something)

(iterate until you thoroughly understand whatever it is you are trying to learn).

Let's examine these steps.

The first is pretty obvious. You didn't "get it" from one lecture. There was too much material. If you were *lucky* and well prepared and blessed with a good instructor, perhaps you grasped *some* of it for a *moment* (and if your instructor was poor or you were particularly poorly prepared you may not have managed even that) but what you did momentarily understand is fading, flitting further and further away with every moment that passes. You need to review the entire topic, as a whole, as well as all its parts. A set of good summary notes might contain all the relative factoids, but there are *relations* between those factoids – a temporal sequencing, mathematical derviations connecting them to other things you know, a topical association with other things that you know. They tell a *story*, or part of a story, and you need to know that story in *broad* terms, not try to memorize it word for word.

Reviewing the material should be done in layers, skimming the textbook and your notes, creating a *new* set of notes out of the text in combination with your lecture notes, maybe reading in more detail to understand some particular point that puzzles you, reworking a few of the examples presented. Lots of increasingly deep passes through it (starting with the merest skim-reading or reading a summary of the whole thing) are *much* better than trying to work through the whole text one line at a time and not moving on until you understand it. Many things you might want to understand will only come clear from things you are exposed to *later*, as it is not the case that all knowledge is ordinal, hierarchical, and derivatory.

You especially do *not* have to work on *memorizing* the content. In fact, it is *not* desireable to try to memorize content at this point – you want the big picture *first* so that facts have a place to live in your brain. If you build them a house, they'll move right in without a fuss, where if you try to grasp them one at a time with no place to put them, they'll (metaphorically) slip away again as fast as you try to take up the next one. Let's understand this a bit.

Your brain is fabulously efficient at storing information in a *compressed associative* form. It also tends to remember things that are *important* – whatever that means – and forget things that aren't important to make room for more important stuff. There are lots of experiments that demonstrate this – the simplest being trying to memorize a string of ten or so numbers at a glance (more than the 7 one can typically get into short term memory).

Try memorizing 1357902468 from just the *one* glance you got reading this sentence. No fair going back and repeating it to yourself, at least while looking at it! Now look at it and try to remember it. One strategy is to just repeat it to yourself until you get it right, but if you stare at it a while and *think*, you'll see that it has a very simple pattern embedded in it.

In fact, this number "compresses" to a single two-step rule – all the odd digits in ascending order followed by all the even digits ditto. You *already know* what a "digit" is, what odd and even numbers are, what ascending versus descending order is. You only need to remember "ascending" and "odd followed by even digits" – everything else is compressed. You will almost certainly be able to remember the digit string *tomorrow* without further rehearsal because of this rule and the fact that it illustrates an interesting point, where if you didn't notice the pattern and just memorized it as a string of "random" numbers, devoid of any meaning, your brain would have little reason to retain it as it is "unimportant". Even if you *forget* this particular string, you may well remember the point and use a *different* string like 1212121212 (five repetitions of 12) to illustrate the *same* point when teaching it to someone else. This is fine! My goal, too, is to teach you *this*, not some particular patterned set of numbers neither of us really cares about.

This ability to compress goes far beyond what I can explain or you can easily imagine. When I play a game of chess, I've forgotten my first five moves by the time I've made my tenth move. By the time the game finishes, I have no idea how I got into the mess I'm probably in. A chess *master*, on the other hand, can *finish* the game and then can recontruct the *entire game* in order, and can criticize each move as they do so. In fact, they can probably remember the entire game they played yesterday, or the one they played last week. They've built a complex structure of associative memory so that they don't remember moves the same way you or I do.

On the other hand, *I* can often remember what mistakes a student of mine made a week after grading one of their papers. I many not remember the student's *name* (no good associative memory there) but I've got great structures for remembering how to solve or not solve physics problems and remember only what the student did *wrong* – I already know how to do what they did right.

This is the goal of your iterated review process. At first you are memorizing things the hard way, trying to connect what you learn to very simple hierarchical concepts such as this step comes before that step. As you do this over and over again, though, you find that absorbing new information takes you less and less time, and you remember it much more easily and for a longer time without additional rehearsal. Sometimes your brain even *outruns* the learning process and "discovers" a missing part of the structure before you even read about it! By reviewing the whole, well-organized structure over and over again, you gradually build a greatly compressed representation of it in your brain and tremendously reduce the amount of work required to flesh out that structure with increasing levels of detail *and remember them and be able to work with them* for a long, long time.

Now let's understand the second part of doing homework – working problems. As you can probably guess on your own at this point, there are good ways and bad ways to do homework problems. The worst way to do homework (aside from not doing it at all, which is *far too common* a practice and a *bad idea* if you have any intention of learning the material) is to do it all in one sitting, right before it is due, and to never again look at it.

It is left as a *homework exercise* for the student to work out why this is a bad idea from the discussion and facts given above. So take a minute and think about it, then turn the page.

Let's see, doing your homework in a single sitting, working on it just one time *fails to repeat and rehearse the material* (essential for turning short term memory into long term in nearly all cases). It *exhausts the neurons in your brain* (quite literally – there is metabolic energy consumed in thinking) as one often ends up working on a problem far too long in one sitting just to get done. It *fails to incrementally build up* in your brain's long term memory the *structures* upon which the more complex solutions are based, so you have to constantly go back to the book to get them into short term memory long enough to get through a problem. Even this simple bit of repetition does *initiate* a learning process. Unfortunately, by not repeating them after this one sitting they soon fade, often without a discernable trace in long term memory.

Just as was the case with memorizing the number above, the problems almost invariably are *not* going to be a matter of random noise. They have certain key facts and ideas that are the basis of their solution, and those ideas are used over and over again. There is plenty of pattern and meaning there for your brain to exploit in information compression, and it may well be *very cool stuff to know* and hence *important* to you once learned, but it takes time and repetition and a certain amount of meditation for the "gestalt" of it to spring into your awareness and burn itself into your conceptual memory as "high order understanding".

You have to *give* it this time, and perform the repetitions, while maintaining an optimistic, philosophical attitude towards the process. You have to do your best to have *fun* with it. You don't get strong by lifting light weights a single time. You get strong lifting weights repeatedly, starting with light weights to be sure, but then working up to the *heaviest weights you can manage*. When you *do* build up to where you're lifting hundreds of pounds, the fifty pounds you started with seems light as a feather to you.

As with the body, so with the brain. Repeat broad strokes for the big picture with increasingly deep and "heavy" excursions into the material to explore it in detail as the overall picture emerges. Intersperse this with sessions where you *work on problems* and try to *use* the material you've figured out so far. Be sure to *discuss* it and *teach it to others* as you go as much as possible, as articulating what you've figured out to others both uses a different part of your brain than taking it in (and hence solidifies the memory) and it helps you articulate the ideas to *yourself!* This process will help you learn more, better, faster than you ever have before, and to have fun doing it!

Your brain is more complicated than you think. You are very likely used to *working hard* to try to *make* it figure things out, but you've probably observed that this doesn't work very well. A lot of times you simply *cannot* "figure things out" because your brain doesn't yet know the key things required to do this, or doesn't "see" how those parts you do know fit together. Learning and discovery is not, alas, "intentional" – it is more like trying to get a bird to light on your hand that flits away the moment you try to grasp it.

People who do really hard crossword puzzles (one form of great brain exercise) have learned the following. After making a pass through the puzzle and filling in all the words they can "get", and maybe making a couple of extra passes through thinking hard about ones they can't get right away, looking for patterns, trying partial guesses, they arrive at an impasse. If they continue working hard on it, they are unlikely to make further progress, no matter how long they stare at it.

On the other hand, if they *put the puzzle down* and *do something else for a while* – especially if the something else is go to bed and sleep – when they come back to the puzzle they often can *immediately see* a dozen or more words that the day before were absolutely invisible to them. Sometimes one of the *long theme answers* (perhaps 25 characters long) where they have no more than *two letters* just "gives up" – they can simply "see" what the answer must be.

Where do these answers come from? The person has not "figured them out", they have "recognized" them. They come all at once, and they don't come about as the result of a logical sequential process.

Often they come from the person's *right brain*. The left brain tries to use logic and simple memory when it works on crosswork puzzles. This is usually good for some words, but for many of the words there are *many possible answers* and without any insight one can't even recall *one* of the possibilities. The clues don't suffice to connect you up to a word. Even as letters get filled in this continues to be the case, not because you don't *know* the word (although in really hard puzzles this can sometimes be the case) but because you don't know how to *recognize* the word "all at once" from a cleverly nonlinear clue and a few letters in this context.

The right brain is (to some extent) responsible for *insight* and *non-linear thinking*. It sees *patterns*, and *wholes*, not sequential relations between the parts. It isn't intentional – we can't "make" our right brains figure something out, it is often the other way around! Working hard on a problem, then "sleeping on it" is actually a *great* way to develop "insight" that lets you solve it *without really working terribly hard* after a few tries. It also utilizes more of your brain – left and right brain, sequential reasoning and insight, and if you articulate it, or use it, or make something with your hands, then it exercieses these parts of your brain as well, strengthening the memory and your understanding still more. The learning that is associated with this process, and the problem solving power of the method, is *much greater* than just working on a problem linearly the night before it is due until you hack your way through it using information assembled a part at a time from the book.

The following "Method of Three Passes" is a *specific* strategy that implements many of the tricks discussed above. It is known to be effective for learning by means of doing homework (or in a generalized way, learning anything at all). It is ideal for "problem oriented homework", and will pay off big in learning dividends should you adopt it, especially when supported by a *group oriented recitation* with *strong tutorial support* and *many opportunities for peer discussion and teaching*.

3 The Method of Three Passes

Pass 1 Three or more nights before recitation (or when the homework is due), make a *fast* pass through all problems. Plan to spend 1-1.5 hours on this pass. With roughly 10-12 problems, this gives you around 6-8 minutes per problem. Spend *no more* than this much time *per problem* and if you can solve them in this much time fine, otherwise move on to the next. Try to do this the last thing before bed at night (seriously) and *then go to sleep*.

Pass 2 After at least one night's sleep, make a *medium speed* pass through all problems. Plan to spend 1-1.5 hours on this pass as well. Some of the problems will already be solved from the first pass or nearly so. *Quickly* review their solution and then move on to concentrate on the still unsolved problems. If you solved 1/4 to 1/3 of the problems in the first pass, you should be able to spend 10 minutes or so per problem in the second pass. Again, do this right before bed if possible and then go immediately to sleep.

Pass 3 After at least one night's sleep, make a *final* pass through all the problems. Begin as before by quickly reviewing all the problems you solved in the previous two passes. Then spend fifteen minutes or more (as needed) to solve the remaining unsolved problems. Leave any "impossible" problems for recitation – there should be no more than three from any given assignment, as a general rule. Go immediately to bed.

This is an *extremely powerful* prescription for deeply learning nearly *anything*. Here is the motivation. Memory is formed by repetition, and this obviously contains a lot of that. Permanent (long term) memory is actually formed in your sleep, and studies have shown that whatever you study right before sleep is most likely to be retained. Physics is actually a "whole brain" subject – it requires a synthesis of both right brain visualization and conceptualization and left brain verbal/analytical processing – both geometry and algebra, if you like, and you'll often find that problems that stumped you the night before just solve themselves "like magic" on the second or third pass if you work hard on them for a short, intense, session and then sleep on it. This is your right (nonverbal) brain participating as it develops intuition to guide your left brain algebraic engine.

Other suggestions to improve learning include working in a study group for that third pass (the first one or two are best done alone to "prepare" for the third pass). Teaching is one of the best ways to learn, and by working in a group you'll have opportunities to both teach and learn more deeply than you would otherwise as you have to articulate your solutions.

Make the learning *fun* – the *right* brain is the key to forming long term memory and it is the seat of your *emotions*. If you are happy studying and make it a positive experience, you will increase retention, it is that simple. Order pizza, play music, make it a "physics homework party night".

Use your whole brain on the problems – draw lots of pictures and figures (right brain) to go with the algebra (left brain). Listen to quiet music (right brain) while thinking through the sequences of events in the problem (left brain). Build little ”demos” of problems where possible – even using your hands in this way helps strengthen memory.

Avoid “memorization”. You will learn physics far better if you learn to *solve* problems and *understand* the concepts rather than attempt to *memorize* the umpty-zillion formulas, factoids, and specific problems or examples covered at one time or another in the class.

Be sure to review the problems one last time when you get your graded homework back. Learn from your mistakes or you will, as they say, be doomed to repeat them.

If you follow this prescription, you will have seen *every assigned homework problem* a minimum of five or six times – three original passes, recitation itself, a final write up pass after recitation, and a review pass when you get it back. At least three of these should occur after you have solved *all* of the problems correctly, since recitation is devoted to ensuring this. When the time comes to study for exams, it should really be (for once) a *review* process, not a cram. Every problem will be like an old friend, and a very brief review will form a *seventh* pass or *eighth* pass through the assigned homework.

With this methodology (enhanced as required by the physics resource rooms, tutors, and help from your instructors) there is no reason for you do poorly in the course and every reason to expect that you will do well, perhaps very well indeed! And you'll still be spending only the 3-6 hours/week on homework that is expected of you in any course of this level of difficulty!

4 Tentative Schedule

The following is a *tentative* schedule for the *current* class (Summer 2010). It probably will not survive intact, as I tend to slow down when people have trouble and speed up when it is smooth sailing, which varies year to year. But it is *a* schedule that will carry us through the material in a timely way, and complete all the required work in the allotted time.

May 19-21

Topics: We will start with a general course description, and review what we will cover, the material above, how to study and do the homework. We will then begin our study of astronomy with some essential *philosophy*, in particular the building of a *worldview*. We will cover: the scientific method, the small angle formula (with a bit of trigonometry and geometry), scientific notation, length and time scales, and some of the units that you will need to know. Following this we will consider the history of astronomy (in particular things accomplished with naked eye observations in the millennia before the invention of the telescope) and we will make our first pass through learning how to navigate the heavens and find "interesting" objects by means of their *declination* and *right ascension* – the "latitude" and "longitude" of the heavens, as it were.

Reading Assignment: This syllabus (completely), Chapters 1 and 2 in Freedman for Thursday and Friday respectively, and *skim* the rest of the textbook to become generally familiar with its contents. Click on at least a couple of links in the "wikilinks" section above and read what you find there, then follow the links in the article itself and read as much as you like – this should be fun!

Homework: Chapter 1- 28, 29, 35, 36, 37, 38. Prepare to discuss 40, 41. When you get a chance (and it isn't cloudy) do 45, 46, 47 from somewhere "dark" on campus, being careful to be safe – do this in groups. If no opportunity presents itself, don't worry – we'll try to schedule a (weather permitting) trip out to our private observation site in Duke Forest perhaps over this weekend and to it together there. The moon will be in its first quarter then, which will give us a great opportunity to look at it as the ancients must have – just barely too small to be able to make out details like mountains and craters and see that it is an approximate *sphere*. Chapter 2- 29, 30, 42, 48. Add activities such as 60 and 61 to your list of observation chores.

Finally, write me a short, *informal* paper or letter that explains why you are taking this course, and what (aside from a science credit) you hope to get out of it. Is there anything in particular you hope to learn? Have you always been curious about science in general, or astronomy in particular? Do you want to know how (as best we can tell) the Universe came to be as it is? Are you hoping to learn enough to pursue amateur astronomy as a hobby, perhaps with your own telescope? Whatever your interests or goals here, articulate them both for *me* and for *yourself* – at the end of the course you can assess whether or not you have accomplished what you set out to accomplish and learned what you hoped to learn.

This homework assignment will be due Monday, 5/24 at the beginning of class.

May 24-28

Topics: Sidereal time, Celestial Navigation, Parallax (from Chapter 2).

All About the Moon and the Tides!

Gravity, orbits, the planets. The problem of retrograde motion on the "spheres". The first *working* solution – the Ptolemaic *geocentric* model. What is good and bad about it (and why one it is bad to have a religious mythology in the way of unbiased reason). Occam/Ockham's Razor – should Nature be "simple"? Copernican *heliocentric* model[2]. Synodic and sidereal periods revisited (opposition and conjunction).

[2]It is worth noting that his "heretical" treatise, *On the Revolutions of the Heavenly Spheres* was published shortly before he died on May 21, 1543 and banned shortly thereafter, while Copernicus was buried in an unmarked grave. The Vatican only struck it from its list of banned books in *1835*. However, his bones were recently *rediscovered* and were *just* reburied (on May 23, 2010), this time with much pomp and circumstance, in *hallowed* ground by the very church in Poland that banned his work. Copernicus, of course, is very dead and does not care, and they *still* haven't taken (the prosecutor of Galileo) Bellarmine's sainthood away, so I tend to view this kind of posthumous grandstanding with

Tycho Brahe's observations. Johannes Kepler and Kepler's Laws. Galileo and (St.) Bellarmine. Newton and Newton's Laws. Newton's Law of Universal Gravitation. Orbits. Kepler's Laws revisited. The Tides once again.

We'll start (but probably not finish) the study of light in chapter 5.

Reading Assignment: Chapters 3, 4 and 5. Also, read the links to all of the people and topics mentioned in the topics section on wikipedia, and follow interesting links from those pages as the mood strikes you.

Also read St. Bellarmine's Letter to Galileo and, if you like, do more google-based work looking up the woes of Copernicus and Galileo, in particular.

Homework: Chapter 3 - You should know all of the "Key Ideas" from the chapter. You should also learn most of the "true facts" about the moon that we talked about in class – its size, probable natural history, approximate radius of its orbit, the inclination of the plane of its orbit compared to the ecliptic, and about the saros and how to predict the interval between "similar" eclipses. Also do problems: 26, 31, 37, 48, 50, 53.

You should note that we are due to have a gangbusters solar eclipse right across NC from the look of it in 2017, a mere seven years from now. Plan your reunion visits early! These problems are due on Friday (before our probable quiz on Chapters 1-3).

June 1-4

Topics: Conclude gravitation/tides and motion of the planets (Chapter 4). Study light: speed of light, light as a wave with frequency and wavelength, the spectrum, interference and diffraction, blackbody radiation (from hot objects, so "temperature" as well), Wien's law, Stefan-Boltzmann law for a blackbody, photon hypothesis, chemically specific spectra (blackbody, emission, absorption), Rayleigh scattering (why the sky is blue and sunset

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a fair degree of cynicism. But it is good that the church can at last – sort of – admit at least some of its many sins against the unbiased pursuit of truth.

red), doppler shift. Also telescopes and how the eye and magnifiers work (Chapter's 5-6).

Homework: Chapter 4: 15, 22, 30, 31, 38, 41, 43, 46, 51, 52, 53 (2-3 items per person, not an essay). Due Thursday. Chapter 5: 10, 13, 14, 15, 19, 22, 28, 31, 36, 38, 45, 46. Due Monday of next week.

June 7-11

Topics: Simple geometric optics (chapter 6): How the eye works, how lenses create magnified images, how a telescope works, how the different kinds of telescope work (e.g. refracting, reflecting, and hybrids such as Schmidt-Cassegrain). Parameters that describe a telescope (to help you one day make such a purchase!): F-Number, magnification, light gathering power, chromatic abberation, limits to angular resolution (diffraction, atmosphere/adaptive optics, light pollution, dew), using e.g. CCD cameras to further increase light gathering power IF one has a rock solid tracking scope. Famous telescopes and radio interferometry telescopes, telescopes that focus on one part of the spectrum.

Our Solar System (chapters 7-16, overlapping into the next week): Kinds of planets: rocky, gas giants, dwarf planets and moons. Names of planets, order, characteristics. Kinetic energy, temperature, and planetary atmosphere. Asteroids. Comets. Cratering and how it relates to age and history and internal geology of planets, moons, etc where we can observe it. Magnetic field and fluid planetary interiors (and Jupiter!).

Homework: Chapter 6: 8, 19, 29, 31, 32, 33, 37, 38. Chapter 7: 22, 24, 25, 29, 34. Chapter 6 due Friday, Chapter 7 due Monday.

It is also time to switch over to "information, not equations" mode. For the rest of the summer session, your standing assignment will be reading the Unverse textbook like a novel, just for the fun and the very cool interesting stuff in it, at the rate of 2 chapters per night (this should take you no longer than a couple of hours, as the chapters aren't that long).

Don't just read! Take notes as you go, highlight things that you want to talk about in class or things you'd like to see or have further explained. There will be a smattering of problems from the chapters as we go, added below, but from now on we really will focus much more on reading and understanding the vast wealth of what is known about our Universe. At this point you know enough of the science that *most of this should now make sense to you*. Of course, whatever *doesn't* should be brought to class and discussed!

June 14-18

Topics: Our Solar System, in detail. Basically we'll try to cover several bodies a day, trying to learn all that is "interesting" about objects in the solar system, concentrating on the Sun, models for formation, and what we have learned from what we can see plus space missions to perform on-site measurements.

Homework: Continue to read 2 chapters (or more) a night for discussion. Check back here as I'll add a handful of homework problems from all of the chapters involved over the course of the week just to give you some concrete questions to study for exams etc.

June 21-25

Topics: Stars, their spectrum, the Hertzsprung-Russell (H-R) diagrams, how they are form*ing* as we speak, their life cycle as revealed by the H-R diagram and parallax-based observations (the way we've been discussing).

Homework: Continue to read 2 chapters a night for discussion. Check back here as I'll add a handful of homework problems from all of the chapters involved over the course of the week just to give you some concrete questions to study for exams etc. This should pretty much exactly take us through the textbook by the end of the session.

June 28-30

Topics: June 28 is last day of class, so we'll wrap up with a discussion and review of everything. June 29 will be the reading period; I'd suggest that we again meet as usual for review and discussion, and then you can retire to study for the final exam, which is from **2-5 pm on June 30th in our regular classroom**.

Homework: Chapter 17: 19, 27, 44, 46, 55. Chapter 18: 11, 13, 18, 44. Chapter 19: 15, 21, 28, 30. Chapter 20: 14, 16, 22, 53. Note that most of this is "review" of the material we covered last week plus the applications of the physics we learned at the beginning.

Be sure to *read the rest of the book!* I will not ask questions on it as we didn't cover it in detail in class, but the chapters on the structure of galaxies and the origin and evolution of the Universe are very interesting. On Monday I will try to go over at least some parts of chapter 26 so we can add some detail to our existing picture of the big bang (and review the evidence, including evidence such as the inference of the expanding Universe and Hubble constant that we have not yet covered). Tuesday is, as I note above, the reading period (which I had forgotten) and there will be no class. I will, however, be available in our classroom during our normal time period and would be happy to hold a review session and answer questions for anybody during that period and for as long afterwards as people wish to stay.

All homework (including any missing assignments) is due by the 28th at the very latest (by University rule). This will let me grade the last of it and give it back to you in time to study from it on the 29th. The long paper you can hand in anytime up to the exam on Wednesday.