The

UNOFFICIAL HANDBOOK

for

NEW GRADUATE STUDENTS

of

Physics & Astronomy

at the

University of North Carolina at Chapel Hill

Third Edition

Compiled by the loving 2nd year graduate students, Summer 2007
Updated Summer 2009
Updated Again Summer 2010

DISCLAIMER: Although the information presented in this handbook proved to be accurate during the 2006-2007 academic year, it may not be completely applicable in further years due to changes made by faculty members and other members of the administration. USE THIS HANDBOOK AT YOUR OWN RISK!!! It is advised that future students check with faculty members to receive up-to-date information concerning policies on the qualifier, classes, etc. Any opinions suggested in this handbook may not necessarily reflect those of the UNC faculty, staff, or other graduate students not partaking in the writing of this handbook.

Future classes are encouraged to annually update and add to the information in this handbook so that it may properly benefit future graduate students of physics and astronomy.

UPDATED DISCLAIMER: The updated information presented in this handbook is accurate according to the 2009-2010 academic year, however it may not be completely applicable in further years due to changes made by faculty members and other members of the administration.

The original editions were found to be useful to the graduate students of the 2008-2010 academic years, hence our desire to update and pass on the information.

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Introduction/Pep Talk

As you embark on this year-long journey with your fellow fledgling grad students, you face a lot of unknown waters. We hope that this handbook will help you navigate safely through some of them. But mapmaking is a tricky thing. After having crossed The Great Waters and struck the dry land of the second year, we have, from memory, tried to chart the route and especially the details surrounding our battle with The Great Sea Monster. We think there's value in this for you who are just now pushing off, but remember, there's no satellite data here: this is cartography in the very early days when Italy might come out looking more like a Salami than a boot.

Maps are also, of course, a flat projection of a three dimensional world. Greenland can end up looking larger than Africa. Looking through these pages, you might get the idea that the qualifier is the most important thing in the world. It's not. You're here to learn physics, to explore the wonders of the workings of the physical world, and to do that among a community of people who share your sense that there's something deep and beautiful to be discovered in all of this. Do what you need to do to jump through the qualifier hoop, but it's just a game you have to play. Try your best to make it playful.

The handbook also doesn't so much tell you about life on the boat as the features of the waters it needs to sail through, so it's not meant to represent the full range of first-year grad student life. It's easy to be daunted by everything you have before you—especially if you think of it out of context. But the context is a good one. You're in a good department surrounded by other good students (pirates notwithstanding) who are generally supportive, and your professors are pulling for you: they really do want the best for you. This context, this life outside the nuts and bolts of doing homework or teaching or getting ready to jump through the hoop of the qualifier is important. The best map in the world doesn't much matter if the morale of the crew is sunk.

While scientists sometimes like to think that they're detached, objective observers, studies show that most of them are in fact human beings and as such have emotional lives of varying degrees of health. You might think that this has nothing to do with grad school, that grad school is only about being able to do physics, but you would be wrong. It's important to support each other, to encourage each other, to maintain connections with friends and family back home, to go outside of Phillips Hall and remind yourself that physics is not the most important thing in life and that even if you feel like you're sinking, the sun will rise in the morning and that that itself is an amazing and beautiful thing.

You will learn things this year that you don't want to. You will have to learn things that are difficult and perhaps not at all enjoyable to grind through, but you will also start to see amazing connections, weird and wonderful things about the world and the math that somehow works to describe and help us discover it. Delight in that. Enjoy that together. Be like a bunch of kids fascinated by the discovery of a line of ants going to an ant hill and wanting to know what's going on below the surface. Mark Steiner is right: "[T]he ability to see things as a child would is one which the great scientists have not lost in all their sophistication."

From the first-year class of the 2006-2007, 2008-2009, and 2009-2010 academic years to yours, we wish you all luck and success during your graduate career in the Department of Physics & Astronomy at UNC.

1. The Doctoral Written Examination (The Qualifier)

1.1 General Overview

As a general requirement of the PhD program in the UNC Department of Physics & Astronomy, each PhD and Master's Degree candidate must pass the Doctoral Written Examination before receiving his or her degree. This examination, also known as the "qualifier," will test students on the core subjects typically covered in the first year of graduate school. These subjects are

PHYS 701	Classical Mechanics	PHYS 734	Statistical Mechanics
PHYS 721	Quantum Mechanics I	PHYS 722	Quantum Mechanics II *or* ASTR 701 Stellar Astro.
PHYS 711	E&M I	PHYS 712	E&M II, ASTR 703 Galactic Dynamics, *or* ASTR 702 High Energy

The Doctoral Written Exam is also used as the written exam for the Master's Degree candidates (the standards for passing are different). The qualifier is administered over the course of two days at the end of the second semester in May, approximately one week after final exams are over. Students typically take the first half of the test, which covers those subjects taken during the first semester, on a Friday; the second half of the exam, which covers the second-semester subjects, is taken on the following Monday.

Note, however, that the testing schedule may vary from year to year. For the 2009-2010 academic year (i.e. the exams given in May 2010), the test was broken into three separate 3-hour blocks with one block on a Friday (Classical Mechanics and E&M I), and the remaining two the following Monday (Statistical Mechanics and QM I followed by QM II and E&M II/ASTR exams depending on track — see below).

1.2 Exam Layout

The qualifier is composed of six individual subject tests, each covering the material of one class taken in the first year. The individual subject tests contain *five* questions each. Of these questions, only the scores on the *best three* problems are taken into account for the grading.

The 2007 qualifier problems are included in this handbook in *Appendix A*.

1.3 Studying for the Qualifier

1.3.1 When to Study

The ‘appropriate’ time to begin studying depends on the student. Some start by working problems and refreshing concepts in January or February; others do not begin until a couple of weeks before the qualifier. By and large, spring break marks a sort of point-of-no-return; students should, in most cases, at least *begin* to study the week after spring break (it is highly recommended, though, that you do enjoy your spring break, for it will be the last true break you have until the qualifier is complete). From this point up until around two weeks before the qualifier, it is also suggested that students work no less than a few problems each day. The majority of studying is done in the two weeks preceding the qualifier, when students typically study during all times of the day they are not sleeping. As finals are usually taken a week before the qualifier or less, a portion of this intense study time must also be devoted to the final exams.

In addition to studying on one’s own, the department may offer various qualifier recitation sessions in the months before the test that are lead by older graduate students (these session were *not* offered in academic year 2009-2010). During these sessions, the recitation leaders will work through qualifier-like problems to help students prepare for the exam.

1.3.2 What to Study

Materials to study should include, most importantly, past qualifiers (see link below to obtain these), physics problem books (see *Appendix B* for book recommendations), and old midterms and final exams (not just from the professors that taught the classes in the previous year but from all possible sources). Concerning past qualifiers, it’s always a good idea to do exams dating back at least seven years. For those entering graduate school during the 2010-2011 academic year, an emphasis should be placed on past qualifiers dating back to 2003, with special emphasis placed on the 2009, 2008, & 2007 qualifiers (particularly the previous year’s exam); going back beyond 2000 would be a waste of time, as exams older than this do not have the same style or difficulty level the current qualifiers display (note the change in difficulty level beginning with the 2005 exam and increasing in 2009, in particular). Also, some types of problems appear on the qualifier more often than others; see *Appendix C* for a breakdown of past qualifier problems according to topics.

Past qualifiers may be obtained from the library’s website through e-res. Go to http://eres.lib.unc.edu.libproxy.lib.unc.edu/eres/courseindex.aspx?error=&page=search, type in ‘physics,’ and they should come right up. Not all of the past qualifier problems, however, are on the website; you may need to go to the librarian in the Math/Physics library and ask for the notebooks containing the old qualifier questions. Many very useful old midterms and final exams can be found by asking older graduate students.

1.4 On the Submission and Grading of the Exam Questions…

Although the faculty members that instructed the classes the qualifier covers are asked to write some of the questions for the exam, problems are also submitted by professors that may not have taught the class previously; do not expect exams from class to mirror the qualifier. Approximately one month before the qualifier is to be taken, the faculty members that will be writing problems are asked to submit their questions to the qualifier committee, which then convenes to select the problems that will appear on the qualifier. Professors may write their own problems or borrow problems from textbooks, problem books, or other schools' qualifiers. More than likely, at least one or two of the problems that appear on each subject test will have been submitted by the professor that taught the subject that year. Given the number of professors involved in writing the qualifier problems, one should keep in mind that the test may include problems on topics not covered in class.

Each problem on the qualifier is graded by the professor who submitted it. Shortly after the exam is taken, the problems are delivered to their corresponding professors who have approximately two weeks to grade them. Each question is worth 10 points. Partial credit is almost always awarded in some form or fashion.

1.5 On the Day of the Test…

Each test day, the exam will generally begin around 9:00am in one of the larger lecture halls in Phillips Hall. Items you should bring with you to the exam are as follows: pencils or pens, paper (although some may already be provided), your PID, a stapler, and a mathematical handbook that doesn't contain any physics formulas (*Schaum's Mathematical Handbook of Formulas and Tables* is highly recommended). Snacks and drinks are typically provided by the staff secretaries during the exam.

A proctor, usually one of the faculty members, will hand out the first two tests at 9:00am and will take it back up 3 hours later. You will be given two tests at a time and it will be up to you to pace yourself. Budget 1.5 hours for each test or 30 minutes per question answered. Once both tests are handed out, students are allowed to step outside the test room as often as needed to take a break or use the restroom. Breaks (including a lunch break) will be given between tests. The schedule on the Monday exam day in May of 2010 was similar to the following:

9:00 am – 12:00 pm	Test #1 and Test #2
12:00 pm – 1:30 pm	Break
1:30 pm – 4:30 pm	Test #3 and Test #4

The schedule on the Friday exam day simply had the two test from 1:30 pm - 4:30 pm. The order and grouping of the tests vary from year to year, but generally the final pair of tests will be either the second-semester physics track exams (QM II and E&M II) or the astronomy track exams.

Students will be instructed to only write on the front side of each sheet of paper and to start each problem on a separate page. Once a subject test is complete, students are to staple the pages of each individual problem together and to place the stapled problems into their corresponding folders at the front of the room so that they may be delivered to the appropriate professors.

NOTE: As the proctor is the master-of-ceremonies of the qualifier events, students should check with him or her before the exam to make sure they are in agreement with the protocol for the exam. In 2009 and 2010 students marked on a spreadsheet which problems they answered for each test to make sure that none of their answers were lost.

1.6 The Decision on Whether a Student Passes the Qualifier

Once graded, all of the problems (with scores attached) are collected by the department chair, who enters all of the students' individual grades for each subject area into one spreadsheet. At this time, only the three best problems for each subject test are taken into account. A faculty meeting is held roughly one month after the qualifier is taken. During the meeting, the spreadsheet of test scores is displayed, and the faculty members vote on which students pass the exam. For this reason, it is wise to make sure your advisor attends the meeting.

In the past, the pass/fail level for the qualifier has been as follows (scores quoted represent the average of all subject test scores):

Pass (without contest) for PhD:	≥ 60%
Pass (without contest) for Master's:	≥ 40%
Fail (without contest) for PhD:	< 40%
Fail (without contest) for Masters:	< 20%
'Gray Zone'	40–60%

In addition to meeting the overall average score requirements shown above, students must earn at least 10 points out of 30 points on each subject test to receive an overall passing mark on the qualifier. Consideration is also given for the number of tests on which a score of 15 or higher is received. For example if a student has a low average due to one *very* low test score (< 10) they will be considered more favorably than a student that has a low average due to 2 or 3 low tests scores (10-15 pts). But in the past, if a student failed even one subject test yet had a respectable overall average on the qualifier, the student failed the entire qualifier and was required to re-take it at a later time. Decisions regarding students whose averages fall in the 'Gray Zone' are primarily made by comparing their overall averages to the 'cutoff' score, which is chosen by the committee members after viewing all of the students' average scores. The 'cutoff' score typically hovers around 50%.

Notification concerning whether students pass the qualifier is normally presented to each student via email by the graduate advisor one week after the committee meeting has adjourned.

Approximately 15 students take the qualifier each year. Although some years have seen all students pass the exam (2004, 2007), one or two students typically do not pass the exam the first time around. If a student fails the qualifier, he or she is given an additional opportunity to pass the exam but must take the *entire* test again as a whole (even though the student may have passed some portions of the exam). The qualifier may be taken again at any time it is offered; a passing score must be earned by the student before any degree is awarded.

1.7 Other Tips and Suggestions

- You're not in this alone! Form study groups to work through problems and help each other out. The class taking the 2007 qualifier even formed a *Facebook* group called "Qualifier Study Group" to help them with their studies. Future classes are encouraged to take over this group and use it for their own benefit.

- You will *not* succeed in studying perfectly for the qualifier. And that's okay.

- Ask for *Starbucks* or *Caribou Coffee* gift cards for Christmas, Easter, your birthday, etc. Coffee shops will quickly become your best friend and ally in the war against the qualifier.

- Write as much as possible for each problem, even physics equations that may loosely be related to the problem at hand; partial credit is almost always awarded!

- At least once before you take the actual exam, work through one of the old qualifiers as if you were taking it for real (time yourself correctly--take breaks as you will receive them). Having a true sense for how much time you have to complete each problem is priceless. Ask other first-year students if they would like to take the mock exam with you in a classroom so that you will have the same background noise conditions you'll have during the real exam.

- Each page you submit for the qualifier must contain your PID, the subject of the problems, the problem number, and the page number of the problem. Before taking the exam, it may be wise to write a blank heading on all of the sheets of paper you will use to write the exam (or, better, create a template in Word or LaTeX and make many copies). An example of this heading may be

______ – #____, pg. ___ of ___ PID: 867-53090 where one would simply fill-in the appropriate information:

EM II - # 3, pg. 2 of 34 PID: 867-53090

It is recommended, though, that one check with the administration before doing this practice during the exam to avoid speculation of cheating.

- Try to get some GOOD sleep the night before the qualifier; if you use sleeping aids, it is recommended that you have them handy just in case you are not able to fall sleep. If you don't use sleeping aids, the night before the exam, however, is *not* the time to start (sleeping straight through the exam because you are drugged out beyond comprehension won't go over well with the faculty members).

- Do NOT put off studying the bulk of the 2nd semester material (Monday test) to the weekend between exams; you will be fully exhausted, burned-out, and mostly useless during the two days in between exams and will regret this decision.

- Don't start or end any addictions that you may have around the time of the qualifier (i.e, if you are addicted to coffee or cigarettes). Quit *after* you have taken the exam; you don't want to stress out your body when your mind is already stressed out enough. If you are going to use caffeine supplements, start early when you begin studying so that by the time the qualifier comes you will know how caffeine affects you specifically and how much you will need.

- Yes, the qualifier is important, but so is your mental health. After studying for six to eight hours *please* take a break--even if it is a small one. Go for a walk on campus or something; walk to *Starbucks* or *Caribou Coffee* to get refueled. Just get out of your office and away from the books for a while. We promise that you will come back refreshed and ready to start studying again.

- Pace yourself on practice qualifier problems. If one problem is taking too long to do, it's okay to give up on it and seek help or solutions. It's not surrendering to the problem--you're learning from what you can't do so when the test comes you will be ready. There will be many problems that seem impossible at first, but you will figure out some way of getting them solved (to some extent). You don't have to be perfect. Remember that partial credit is a very important tool to the physics student.

2. Milestones of Graduate School in Physics & Astronomy

2.1 Classes

2.1.1 Required Classes

The physics graduate program at UNC requires students to take ~10 graduate-level classes. The first six of these classes are introductory-level classes and are typically taken in the first year of graduate school. The first semester classes are (listed with the textbooks commonly used)

PHYS 701	Classical Mechanics	(Goldstein)
PHYS 721	Quantum Mechanics I	(Sakurai)
PHYS 711	Electromagnetic Theory I	(Jackson)

The second semester classes are (QM II & EM II are replaced with ASTR classes for those concentrating in astronomy/astrophysics)

PHYS 741	Statistical Mechanics	(Huang or Pathria)
PHYS 722	Quantum Mechanics II	(Sakurai)
PHYS 712	Electromagnetic Theory II	(Jackson, Rybicki & Lightman)
ASTR 703	Galactic Dynamics	(Binney)
ASTR 702	High Energy	(Shapiro & Teukolsky)
ASTR 701	Stellar Astrophysics	(Clayton, Ostlie & Carroll)

See *Appendix D* for a detailed listing of the textbooks generally used for these first-year courses.

Beyond these introductory classes, students must take three advanced-level courses (ones that require an introductory-level class) and an enrichment course outside of your area of study. In some cases, students may meet multiple requirements with a single class (such as an advanced-level class outside of your region of focus), resulting in taking fewer classes. Students should also check for classes offered in other departments and at other institutions (Duke or NC State) that may meet some of these requirements. The graduate advisor will keep students up-to-date on course requirements during advising meetings.

2.1.2 Class Grades

Letter grades are not assigned in graduate-level physics classes at UNC. Instead, students are given one of the following marks: high pass, pass, low pass, fail. Professors most frequently assign the grade of ‘pass’ to students in their classes. High passes are reserved for students who display stellar performances during the semester. Low passes are assigned to those students who did not exhibit a reasonable amount of effort in class work and on exams (rarely handed out).

Throughout the course of graduate studies, students are allowed to receive a maximum of two 'low pass' scores. A third 'low pass' or a single failing grade results (usually) in the student being taken out of the graduate program.

2.2 Advising

Twice a year, typically in November and April, each graduate student meets with the graduate student advisor. During the meeting, students determine which courses to take in the following semester and update the graduate advisor on his or her research progress. Students beyond the first year are required to bring a written statement describing the current state of their work towards the Master's Degree or the PhD.

2.3 Finding an Advisor

Although the first year of graduate school will be busy with classes, homework, teaching, and the qualifier, it is highly advised that students begin to find an advisor before the summer starts. Attending various group meetings and scheduling meeting times with particular professors are both good starts to determining which research group may be the one to join. Students should also not hesitate or be embarrassed to approach professors and ask them what projects they're working on and whether they may join their research group. Do not be discouraged, however, if it does not work out with a particular advisor; graduate students often go through several advisors before finding the right pairing.

2.4 The Qualifier

At the end of the first year, a written exam is administered testing your knowledge of physics. It's best not to get too worked up over it. See *Section I* for details.

2.5 Master's Degree Presentation

Candidates for the Master's Degree must give a presentation on their research accomplishment before receiving a degree. This presentation is carried out in the same manner as that for the preliminary examination presentation (described in Section 2.6).

2.6 The Preliminary Examination

Before diving into heavy dissertation work, students are required to hold a preliminary exam presentation (oral exam). For this presentation, students meet in one of the conference rooms with their dissertation committee members (chosen by the student) and any members of the public that decide to attend the presentation. Students' presentations should last around 30 minutes. After the initial presentation, the general public is asked to leave the room, and the committee members ask the student various questions concerning the research topic during a private meeting. Once this session is complete, the committee members ask the student to exit the room, and they vote on whether the student should 'pass' the preliminary exam and continue on with the research topic discussed to the PhD. *For a more detailed description of this process and to ensure the accuracy of the information presented above, consult the graduate student advisor.*

2.7 Dissertation Defense

The layout of the dissertation defense is quite similar to that described in the preliminary examination section. The PhD candidate first gives a presentation of his or her thesis work to the committee members and the general public. Afterwards, the committee members ask the student questions once members of the public have vacated the room. The decision of whether to award the candidate the PhD is made by the committee members in a private meeting following the questioning session. *For a more detailed description of this process and to ensure the accuracy of the information presented above, consult the graduate student advisor.*

2.8 Outline of the First Year

May – July

-Graduate from your respected undergraduate institutions – congratulations!
-Enjoy your two months of freedom unless you are involved with summer research, and then there's not much to say….

August

-Move to North Carolina, specifically the OC (fortunately, it's not like the television show)
-Teaching assistant training/physics department orientation (we didn't like it either)
-Fill out paperwork and obtain student identification card (good for library books, work-out center, basketball games, etc.)
-Graduate School Orientation/Center for Teaching and Learning (CTL) Orientation
-Advising and Registration for classes
-Start Classical Mechanics, Quantum Mechanics 1, and Electromagnetic Theory 1 (whee!)

September

-Think about quitting graduate school – but then you give it another go.

October

-Midterms in CM, QM1, EM1

-Dress up for Halloween, pass candy out to your lab students, and attend festivities on Franklin St. (pass by the department office to see what Sallie dressed up as for Halloween)

November

-Advising for spring semester

-Think about quitting again but realize how close you are to finishing the semester and decide to go on…

December

-Finals in CM, QM1, EM1

-Winter Break – Happy Hanukkah! Merry Christmas! Happy Kwanzaa!

January

-Final decision about whether you will go the astrophysics or physics route

-Start Statistical Mechanics, Quantum Mechanics 2, Electromagnetic Theory 2 (physics)

-Start Statistical Mechanics, Stellar Astrophysics, Galactic Dynamics (astrophysics)

February

-Depending on where you fall, Happy Valentine's Day! or Happy Single's Awareness Day!

March

-Midterms in SM, QM2, EM2, and the ASTRO courses

-Sign up for the Doctoral Written Exam

-Spring Break!!!

April

-Advising for fall semester

-Think about quitting yet again; fill out appropriate job applications to McDonalds, Burger King, etc., but retract these applications when you realize you will go on because you are so close to being finished with the first year (the most difficult of years, in many respects)

May

-Finals in SM, QM2, EM2, and ASTRO courses

-Take the Qualifier (approximately one week after finals end)

-Rejoice in being done with the Qualifier!

-Relax!

Summer

-Revise this handbook!

3. Teaching Assistant Information

Most of the information concerning the teaching assistantship duties may be found on the TA home page at http://www.physics.unc.edu/labs/TA/. This handbook only presents minor details of the TA position that might not be discussed on the website.

3.1 Funding for Graduate Students

Graduate students in the Department of Physics & Astronomy receive funding through teaching assistantships, research assistantships, fellowships, or other grants. The majority of first-year graduate students are on a teaching assistantship, switching (on the whole) to research assistantships in the second and third years. Some students, however, even teach into their 4th and 5th years as a graduate student. No matter the source, the UNC Physics & Astronomy Department will make sure that its students are funded somehow.

3.2 Departmental Teaching Requirement

Each student is required to teach a total of *two semesters* of labs or recitations before receiving a degree. The majority of students will have fulfilled this requirement after the first year.

NOTE: What is meant by 'two semesters' is not yet known completely (does this mean one must teach six labs (two full semesters) or just teach something over two semesters?). Check with the Graduate Advisor for clarification.

3.3 Grading

As a TA, grading will quickly become the bane of your existence. Lab TAs are responsible for grading lab reports (~9 per student) and the lab exam. Keeping on top of grading makes the TA's life easier to handle as far as classes and doing homework goes. Do NOT allow yourself to get the end of the semester with 100 ± 7 lab reports to grade that have stacked up over the course of the lab!

3.4 Q & A

1) What if I make a mistake in front of the students. Will they think I'm stupid?

Do you think a professor is stupid when he or she makes a mistake at the board in one of your classes? Of course not. Likewise, students generally understand that it is difficult to teach at the board to a room full of people and will not think anything of a TA making a mistake. Turn your mistakes into opportunities for your students to correct them. If you spot it before they do, ask them to find it and point it out. If they spot it before you do, simply correct it on the board and commend the student who found it for spotting it—don't think anything more of it than that or overly apologize for making it. Mistakes you make will only stand out if you, the TA, dwell on them.

2) What is the general layout of a typical physics lab session?

~20 minute pre-lab presentation by the TA followed by the students performing the given laboratory exercise. Sometimes students will finish early, in which case you may allow them to leave early. Other times, experiments may take much longer than anticipated, and TAs may have to cut some sections of the experiment out.

3) I haven't really ever taught before, plus I get really, really nervous when I talk in front of people. Now throw in all the physics, and I'm a mess. Don't get me wrong, I understand physics, but teaching it to other people so they can also understand is hard for me. Any tips?

The students in your lab will look to you for guidance and will accept as true most anything you tell them about physics. Turn their trust in you into confidence, and your teaching will go smoothly. If you have trouble speaking in front of a group, do a run-through of your pre-lab presentation a few times before giving the real one. This will relax you during your actual pre-lab. Remember, you truly do know the material you are teaching to them very well whether you think you do or not (otherwise, you wouldn't have been accepted to graduate school).

4) How much should I provide in prepared templates? In other words, should I make Excel spreadsheet templates for them to just fill in with data, or should I just give a brief overview on how to use Excel and then let them figure it out on their own?

Prepared templates are a good idea for many of the labs. However, TAs must be careful not to do too much of the work for the students in the preparation of these templates, such as setting up error and data analysis formulae. Setting up an Excel template structured in a way that allows students to take data in a time-efficient and organized manner, on the other hand, would be a good way to utilize a template.

5) What about giving worksheets instead of lab reports? I've seen other TAs do it, should I?

The only true requirement for the lab reports is that students write *at least* two full-written, formal lab reports. For the other labs, it is common to use the *webLabs* system for reports. After the lab exam has been given, it is quite common and, in most cases, acceptable for TAs to simply assign worksheets to the students instead of requiring them to complete reports (although one should check with Duane to make sure this is okay). These worksheets may include questions you have made up yourself concerning the lab, or you may simply only require your students to turn in data from the experiment, which will count as their lab report grades. Many older graduate students that have taught labs before have worksheets already made up for some of the experiments, so TAs may want to ask around for worksheets before making their own from scratch.

6) How about handouts? Is there a real need to give handouts as a supplementary guide to the lab book? How well written is the lab book?

TAs may, of course, make supplementary handouts for their students if they so desire. However, the lab manual is written fairly well for most of the labs, so handouts are generally not needed. A few of the experiments, though, have procedures that are quite involved and lengthy. Time may be used more efficiently by the students in these cases if the TA were to make up a handout summarizing the main procedure points for the experiment. TAs can easily determine which experiments fall under this category.

7) How strict should I be when grading labs? Is there a certain average score I should shoot for?

The overall lab report average for your students should fall around 85%. This is a good indicator of how hard or easy of a grader a TA is. If your lab report average falls way above or below this value, feel free to adjust the level of your grading accordingly so that your lab report average falls at a reasonable value. Duane will update you regularly during the TA meetings on where your averages fall with respect to the other lab sections.

The overall lab average for each student (including the lab exam) usually falls around 80%. Given the 85% lab report average quoted above, it is easy to see that the overall grade is substantially pulled down by the lab exam average, which generally falls around 70% for each section.

8) Is it okay if I sit in on other TAs' labs to get a feel on how more experienced TAs handle the lab?

This is a great idea and is highly recommended. Contact any other TA teaching the same lab you are and work this out with him or her.

9) Not only do I have to TA a lab, but I have to tutor in the PTC??!!? Do I only answer lab related questions from my students since it's technically "office hours"?

The Physics Tutorial Center (PTC) is open to *all* students in undergraduate physics classes. TAs fulfilling their hours in the PTC are required to address questions posed by *any* student in the PTC, not just students that are enrolled in the TA's lab section. During the course of the semester, you may have to answer questions ranging from students in PHYS 100-level classes to those taking PHYS 117. From time to time, physics majors and other science-majored students taking advanced-level physics class may even ask the TA on duty questions. Working in the PTC is a great way to stay on top of old material and work on problem-solving strategies, both of which will help you prepare for the qualifier.

10) When I'm teaching during the pre-lab, what is the one main thing I should make sure that the students take away from it?

For some of the experiments, students will not have covered the material in the class before doing the experiment on a given topic. In this case, the TA's pre-lab will be the first chance students have to hear about a particular topic in physics. Making sure the students have a good grasp of the underlying topic or idea of a lab is of the utmost importance, as is their having a clear knowledge of the procedure they are about to go through in lab. Find out whether the students have discussed the experiments' ideas in class *before* you teach each week, and adjust your pre-lab accordingly.

11) If I miss a TA meeting, is it that critical? What really goes on during the meeting that's so important?

During the TA meetings, Duane will address any issues TAs had with the previous week's experiment and will review issues and give recommendations concerning the experiment TAs will cover the next week. These meetings are required for all TAs. Even though some of these meetings may seem pointless, remember that you are getting paid to be a TA (quite well, in fact, when you convert it into an hourly figure) and that these meetings are just one more aspect of your job. Duane understands how difficult the first year is and will be forgiving if you miss a few of the TA meetings during the semester. If these meetings start to run too long and the topics at hand get completely off-track, it would be reasonable to bring up the issue with Duane so that they meetings are once again held in a time-efficient manner.

12) What if I do a 1/3 TA as grading for a class - does that count toward the teaching requirement?

No, the teaching requirement must be met by teaching labs or recitation sections. Grading is not recognized as an experience in teaching.

13) Hmmm...this all still seems a little overwhelming - TA-ing, tutoring, attending classes, doing homework, studying for the qualifier.....how do you manage to do everything without losing sanity?

Although losing sanity is likely to occur once or twice during the first year given the number of responsibilities students have, simply keeping on top of your tasks (grading on time, most importantly) will give you a sense of control over all of your work and make managing your life that much easier. Keeping track of your responsibilities with a daily planner or some other type of calendar is highly-recommended.

4. Other Useful Information

4.1 Commuting to Campus

Parking around the UNC-Chapel Hill campus is scarce and difficult to come by; those TAs teaching night labs can obtain a parking decal to park on campus by talking with Beverly Loftin. The city of Chapel Hill owns a few parking lots that cost around $1 an hour, including one at the intersection of Church St. and Franklin St. and a few on Rosemary St. in the downtown area (these lots are free after 8pm and all day on Sundays). One can also park in the visitor's lot in front of the Morehead Planetarium for an hourly fee. On the weekends and after 5:30pm on weekdays, most of the UNC parking lots are open to anyone (the Swain Lot gates, however, go down on Saturdays after 3:30pm, so be careful about getting stuck there after this time and having to pay to get out). One can often find a free spot right behind Phillips Hall.

The easiest way to get to campus each day and around town is via the Chapel Hill Transit bus system. See their website (http://www.townofchapelhill.org/index.asp?NID=72) for bus routes and schedules (including a live map of current vehicle locations).

Also see http://regweb.unc.edu/links/public_safety.php for other transportation information.

4.2 Eating Out When on Campus

Some graduate students eat on Franklin St., in Lenoir Hall, or pick up a snack from the YMCA building (near Phillips Hall) when on campus; most prefer to bring their own lunches. Vending machines are located in the basement of Phillips Hall. See OSSA Services Committee's Survival Guide for a listing of restaurants (http://www.unchost.org/ossa/docs/OSSA_survival_guide.pdf).

4.3 Becoming a North Carolina Resident

The Physics & Astronomy Department highly recommends that each student become a resident of NC as soon as possible, as the difference in tuition for out-of-state and in-state students is significant. In most cases, students can apply for residency after living in NC for one year. Items new students should complete to help obtain the status of resident are obtaining a NC driver's license, registering your vehicle with the NC DMV (http://www.ncdot.org/dmv/), and registering to vote in NC, which can be done when you obtain your driver's license. The NC residency application may be completed online at the following URL: https://cfx3.research.unc.edu/grad_res/index.cfm.

4.4 Tuition & Other Fees

The department pays for each student's tuition for a total of five years of graduate school; thereafter, it is the *student's* responsibility to pay for tuition. For this reason, it is recommended that each student obtain the status of resident in NC *before* the fifth year of graduate school. Although tuition is waived for five years, students are responsible for paying student fees each semester amounting to ~$800. These fees can automatically be taken out of students' paychecks over the course of 5-6 pay periods each semester. Contact the appropriate secretary to do this.

4.5 Allocated Webspace for Graduate Students

All graduate students are allotted web space in *afs/users/FIRST LETTER OF YOUR ONYEN/ONYEN* (get here by going to the X: Network Drive under 'My Computer' on Windows machines). The URL to your webspace is www.physics.unc.edu/~YOURONYEN. Graduate students are also encouraged to edit their profiles on the departmental webpage (http://www.physics.unc.edu/directory/), where a link to your website may be posted.

Appendix A (The 2007 Qualifier)

NOTE: The 2007 Qualifier questions have been copied word-for-word as they appeared on the qualifier, including grammatical errors and misspellings.

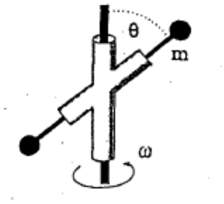
CM-1

Consider a ball of mass m dropped and energy E bouncing elastically up and down (so that energy is conserved).

(a) Sketch the trajectories in phase space
(b) Express the Hamiltonian in terms of the action variable J and calculate the frequency of oscillation in terms of E.

CM-2

Consider a massless rigid rod of length l with a ball of mass m at each end, rotating around an axis that runs through the center of mass as shown (θ <90°). The radius of each ball is negligibly small.



(a) What are the principal moments of inertia I_i in the body-fixed frame?
(b) The components of w are constant in the body-fixed frame. Find the components of L in that frame, and draw the direction of L.
(c) Use Euler's equations to find the direction of the torque N (in the body-fixed frame) required to keep the object rotating as in the figure. Draw the direction of N.

CM-3

Consider the "point" transformation from the coordinates $q_1 ... q_N$ to another set $x_1 ... x_n$. Show that if Langrage's equations hold for the q's they also hold for the x's provided the functions $x_i(q_1 ... q_N, t)$, $i=1, N$ satisfy a certain mathematical condition. What is the condition and what does it mean physically?

CM-4

A particle of mass m is subject to a central force $F(r) = -V'(r)$. Assume the particle moves on a circular orbit of radius $r=R$, and that in that orbit its angular momentum is L.

Assume very little specific information about the potential away from $r=R$ except that is has a Taylor series expansion

$$V(r) = V(r) + V'(r)(r-R) + \frac{1}{2}V''(R)(r-R)^2 + \ldots$$

(a) Determine the angular momentum L, energy E, and angular velocity Ω_ϕ of the circular orbit.

(b) Consider a nearly circular orbit with the same angular momentum. Work out the linear perturbation equation for radial motion.

(c) What condition on the derivative $V'(R)$ and second derivative $V''(R)$ must hold for the perturbed orbit to be stable?

(d) After finding the frequency Ω_r of radial motion, give an expression for the change in apsidal angle $\Delta\phi$ that occurs per radial oscillation.

CM-5

The motion of a relativistic particle of mass m in a static potential $V(x)$ can be obtained from the Lagrangian

$$L = -mc^2\left(1-\frac{v^2}{c^2}\right)^{\frac{1}{2}} - V(\mathbf{x}).$$

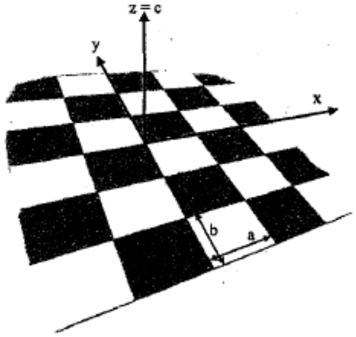
(a) Write out Lagrange's Equations.

(b) Find the canonical momentum p and write out the Hamiltonian $H(x^i, p_i)$(in terms of position and momentum).

(c) Is H a constant of the motion?

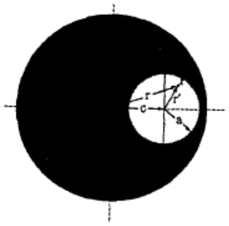
EM I – 1

The figure below shows an infinite checkerboard in the x-y plane in which the grey boxes are held at a potential $+V_o$ and the white boxes are at $-V_o$. The boxes have dimensions a x b as shown. Find the potential at all points z > 0, assuming the $z=c$ plane is held at zero potential.



EM I – 2

A straight, cylindrical conductor carries a constant current density *J*. A cylindrical cavity of radius *a* is cut into the conductor, along an axis parallel to that of the conductor and offset by a distance *c*. A cross-sectional view is shown below. Assuming *J* is directed into the page, what is the magnitude and direction of the magnetic field at a point ***P*** within the cavity?



EM I – 3

Consider a uniformly charged sphere of radius *2a* and charge density ρ . Assume the sphere contains a spherical cavity or radius a/2 that is centered at (0, 0, *3a*/2), while the larger sphere is centered at the origin. Find the force on a point charge of charge *q* located at (0, 0, *a*).

EM I – 4

Consider a point charge of charge *q* that is located at a height *h* above a large pool filled with a perfectly conducting fluid that has a mass density ρ . The pool is located at the surface of the earth. Assume that the deviation of the surface caused by the electrostatic force from the charge is much smaller than *h*.

1. Find the electric field at the surface of the fluid.
2. The electrostatic force per unit area experienced by a surface charge density at a surface where the electric field is discontinuous is given by:

$$\vec{f} = \sigma(\overrightarrow{E_1} + \overrightarrow{E_2})/2$$

where $\overrightarrow{E_1}$ and $\overrightarrow{E_2}$ are the electric fields at the two sides of the surface. Given this, find the equation of the surface the fluid assumes under the electrostatic force of the charge.

EM I – 5

A conductor at potential *V=0* has the shape of an infinite plane except for a hemispherical bulge of radius *a*. A charge *q* is placed above the center of the bulge, a distance *p* from the plane (or *p – a* from the top of the bulge). What is the force on the charge?

QM I – 1

Consider the coherent state of a one-dimensional simple harmonic oscillator $|\lambda\rangle = e^{-\lambda^2/2} e^{\lambda a^+} |0\rangle$, where λ is a number and a^+ is the creation operator. (a) Show that the coherent state satisfy the minimum uncertainty product for x and p. (b) Do an order-or-magnitude estimate for the value of λ for a macroscopic pendulum oscillator with string length of 1m, ball mass of 1kg, and oscillation amplitude of 10 degrees.

QM I – 2

Answer these questions briefly:

(a) Write down the relationship between the wave function in the coordinate space and that in the momentum space.
(b) Describe briefly what is the Aharnorov-Bohm effect.
(c) Write down the Wigner-Eckart theorem.
(d) Describe briefly the experiment that demonstrates the gravity-induced quantum interference effect.
(e) Derive the equation of motion for the time evolution of the density operator.

QM I – 3

Consider a beam of spin ½ particles in the pure state $|n,+\rangle$, where n is a unit vector with polar angle θ and azimuthal angle ϕ. Use the eigenvector of S_x, $|+\rangle$, $|-\rangle$ as the basis.

(a) Show explicitly that $|n,+\rangle = \cos(\theta/2)|+\rangle + e^{i\phi}\sin(\theta/2)|-\rangle$ is the eigenstate of $S_n = S \bullet n$ with the eigenvalue $\hbar/2$?

(b) A S_y Stern-Gerlach-type measurement is performed on the beam. What is the probability of finding the value $-\hbar/2$?

(c) If the measurement of Sx was done first, independent of its outcome the measurement of S_y is done next. What is the probability of finding the value $-\hbar/2$?

QM I – 4

Consider a particle of charge e and mass m in constant crossed **E** and **B** fields:

$$\mathbf{E} = (0, 0, E),\ \mathbf{B} = (0, B, 0),\ \mathbf{r} = (x, y, z)$$

(a) Write the Schrödinger equation, in a convenient gauge.
(b) Separate variables and reduce it to a one-dimensional problem.
(c) Calculate the expectation value of the velocity in the x-direction in any energy eigenstate sometimes called the drift velocity.

QM I – 5

A particle of mass m and charge q sits in a harmonic oscillator potential $V = k(x^2 + y^2 + z^2)/2$. At time t=-∞ the oscillator is in its ground state. It is then perturbed by a spatially uniform time-dependent field

$$\mathbf{E}(t) = Ae^{-(t/\tau)^2}\hat{\mathbf{z}}$$

Where A and τ are constant. Calculate in lowest-order perturbation theory the probability that the oscillator is in an excited state at t=+∞.

SM – 1

Consider a molecule as a rigid motor with moment of inertia I. Its energy levels associated with rotation are given by

$$\varepsilon_j = \frac{h^2}{2I} j(j+1) \text{ with generacy } g_j = 2j+1 \text{ and } j=0,1,2,...$$

Show that the heat capacity per molecule associated with rotation is given by

$$C = 3k\left(\frac{2\theta_r}{T}\right)^2 \exp\left(-\frac{2\theta_r}{T}\right); \theta_r \equiv \frac{h^2}{2Ik}$$

when $T \ll \theta_r$. Reminder: $U = -\partial \ln Q / \partial \beta$.

SM – 2

Consider an ideal gas in a one-dimensional channel of length L. The energy of the particle is given by $E = \frac{p^2}{2m} - \varepsilon_o$.

(a) Show, using the classical approach, that the partition function of one particle is given by $Q_1(T,L) = \frac{L}{\lambda} e^{\varepsilon_o/kT}$. Reminder: $\int_0^\infty e^{-x^2} dx = \sqrt{\pi}/2.$

(b) What is the partition function of N indistinguishable particles (just write down the answer)?

(c) Calculate the chemical potential of this system of N particles at temperature T.

SM – 3

Consider a system of N non-interacting particles that have two possible energy states, $E = 0$ or $E = \varepsilon$. Find the temperature of the system as a function of the total energy. What happens to the temperature of the system when the total energy is greater than $N\varepsilon / 2$? Assume N to be a large number.

SM – 4

A gas obeys the following equation of state (the *Dieterici* equation):

$$P(v-b) = k_B T \exp(\left(-\frac{a}{k_B T v}\right)$$

where $v=V/N$ and a and b are constants. Find the critical point (P_c, T_c, v_c) for this gas, if it exists.

SM – 5

A wire of length l and mass per unit length μ is fixed at both ends and tightened to a tension τ. What is the rms fluctuation, in classical statistical mechanics, of the midpoint of the wire when it is in equilibrium with a heat bath at temperature T? A useful series is

$$\sum_{m=0}^{\infty}(2m+1)^{-2} = \frac{\pi^2}{8}$$

QM II – 1

Consider a charged particle with charge q in a 2-D isotropic harmonic potential $V(x) = \frac{1}{2}Mw^2r^2$. A weak electric field E is applied along the diagonal direction (making 45 degree with x axis). (a) Using perturbation theory to calculate the ground state energy to the second order in E. (b) Solve the problem exactly and compare the result with part (a).

QM II – 2

Using the variation principle to estimate the ground state energy of the 1-D simple harmonic oscillator. Explain your choice of the trial wave function.

QM II – 3

Consider the scattering of a plan wave (with momentum k) by a 3-dimensional spherical potential.

(a) If the potential is a hard sphere with a radius R what is the phase shift and the total scattering cross section for the s-wave scattering.

(b) If the potential is such that the phase shift of s, p, d, wave scattering are $\pi/2$, $\pi/4$, $\pi/6$, what is the total scattering cross section.

QM II – 4

An isolated hydrogen atom has a hyperfine interaction between the proton and the electron spins ($\mathbf{S}_1$ and $\mathbf{S}_2$, respectively) of the form $J\,\mathbf{S}_1 .\, \mathbf{S}_2$. The two spins have magnetic moments $\alpha\mathbf{S}_1$ and $\beta\mathbf{S}_2$, and the system is in a uniform magnetic field **B**. Consider only the orbital ground state.

(a) Find the exact energy eigenvalues of this system and sketch the hyperfine splitting spectrum as a function of magnetic field.

(b) Calculate the eigenstates associated with each level.

QM II – 5

A particle of total energy $E = h^2\alpha^2/(2m)$ moves in a series of N contiguous one-dimensional regions. The potential in the n^{th} region is $V_n = -(n^2 - 1)E$, where $n = 1,2,.....,N$

All regions are equal width π/α except for the first and the last, which are of effectively infinite extent. Calculate the transmission coefficients for a particle incident from either end.

EM II – 1

A thin, straight, conducting wire is centered on the origin, oriented along the z-axis and carries a current $\mathbf{I}=I_0\cos\omega_0 t\ \hat{z}$ everywhere along its length *l*. Define $\lambda_0 \equiv 2\pi c/\omega_0$.

a) What is the electric dipole moment of the wire?

b) What are the scalar and vector potentials everywhere outside the source region (*r* » *l*). State your gauge and make no assumptions about the size of λ_0.

c) Consider the potentials in the regime *r* » *l* » λ_0. Describe (qualitatively) the radiation pattern and compare it to the standard dipole case, where *r* » λ_0 » *l*.

EM II – 2

A Δ^+ hadron decays at rest into a proton and a pion,

$$\Delta^+ \text{ ® } p^+ + \pi^0 .$$

The rest mass of the Δ resonance is assumed to be $m_\Delta = 1620$ MeV/c^2, while the rest mass of the proton is $m_p = 938$ MeV/c^2 and the pion has $m_\pi = 135$ MeV/c^2.

(a) Using energy-momentum four-vectors, obtain the final state energy E_p, Lorentz factor γ_p, and the speed v_p/c for the proton.
(b) Obtain the comparable quantities for the pion, E_π, γ_π, and v_π/c.

EM II – 3

Consider a circular current loop of radius a and of infinitesimal cross section that is confined to the $z = 0$ plane. Let there be a sinusoidally varying current $I\exp(-i\omega t)$ in the wire, giving rise to a complex amplitude for the current density

$$\vec{J}(\vec{x}') = I\sin(\theta')\delta(\cos(\theta'))\frac{\delta(r'-a)}{a}\vec{e}_\phi .$$

a) Show that the complex amplitude of the magnetic moment is

$$\vec{m} = \frac{1}{2c}\int d^3x'\vec{x}'\times\vec{J}(\vec{x}') = \frac{\pi a^2}{c}I\vec{e}_z .$$

In the multipole expansion, a time-varying magnetic dipole gives rise to a vector potential field in the radiation zone of,

$$\vec{A} = ik\frac{e^{ikr}}{r}(\vec{n}\times\vec{m}).$$

b) Use this to compute the distant ($kr \gg 1$) magnetic field and electric field.

c) Compute the angular distribution of the radiated power $dP/d\Omega$ and sketch the antenna pattern.

EM II – 4

The general expression for the radiated energy spectral-angular distribution of a relativistic electron is

$$\frac{dW}{d\omega d\Omega} = \frac{e^2\omega^2}{4\pi^2 c}\left|\int dt'\vec{n}\times(\vec{n}\times\vec{\beta})\exp[i\omega(t'-\vec{n}\times\vec{x}(t')/c)]\right|^2 ,$$

which is derived using the Lienard-Wiechart expression for the radiative part of the electric field.

Consider a nucleus that suddenly emits a beta particle. The sudden appearance of the beta decay electron is associated with a burst of electromagnetic radiation also, called appearance radiation. It arises because the electron's velocity and position are defined only for $t' > 0$:

$$\vec{\beta} = (0,0,\beta) \text{ for } t' > 0,$$

and

$$\vec{x} = (0,0,c\beta t') \text{ for } t' > 0.$$

With the observation direction taken to be $\vec{n} = (\sin\theta, 0, \cos\theta)$, show that the appearance radiation for beta decay is given by

$$\frac{dW}{d\omega d\Omega} = \frac{e^2}{4\pi^2 c}\frac{\beta^2 \sin^2\theta}{(1-\beta\cos\theta)^2}.$$

EM II – 5

A *tenuous plasma* consists of free electric charges of mass *m* and charge *e*. There are *n* charges per unit volume. Assume that the density is uniform and that the interactions between the charges may be neglected. Electromagnetic plane waves (frequency ω, wave number *k*) are incident on the plasma.

(a) Find the conductivity σ as a function of ω.
(b) Find the dispersion relation, i.e., the relation between *k* and ω.
(c) Find the index of refraction as a function of ω. The plasma frequency is defined by $w_p^2 \equiv 4\pi n e^2/m$.

What happens if $\omega < \omega_p$?

Astro I – 1. Energy transport

The equation of radiative transfer in a plane parallel, gray atmosphere can be written as:

$$\cos\theta \frac{dI}{d\tau_v} = I - S$$

where I is intensity, τ_v is the optical depth measured vertically from the surface, and S is the source function.

a) The source function S describes how propagating photons are removed and replaced by photons from the gas. Mathematically it is the ratio of the emission coefficient to the absorption coefficient. In local thermodynamic equilibrium it is equal to the Planck function B. Under what conditions (i.e. at what place in a star) is the intensity I also equal to B? Explain your answer.

b) Starting with the equation above, derive the equation of transport used in stellar interiors:

$$\frac{dT}{dr} = -\frac{3}{4ac}\frac{\bar{\kappa}\rho}{T^3}\frac{L_r}{4\pi r^2}$$

c) Use the condition for convection to show the limiting case for radiative transport is:

$$\frac{dT}{dr} = -\left(1 - \frac{1}{\gamma}\right)\frac{\mu m_H}{k}\frac{GM_r}{r^2}$$

(Hint: You will need the adiabatic relation $PV^{\lambda} = C$, and the equation of hydrostatic equilibrium to get the result in this form)

Astro I – 2. Stellar dimensional analysis

a) Use the equation of hydrostatic equilibrium in difference form to derive the dependence of stellar central pressure on total stellar mass and radius. Assuming an ideal gas equation of state, what is the mass and radius dependence of central temperature? (assume constant composition, homologous density profiles)

b) Now assume that nuclear fusion is a "perfect thermostat" that keeps the core temperature identical for all hydrogen burning stars. What is the predicted mass-radius relationship for the main sequence?

c) Use the equation of radiative transport in difference form to derive the mass-luminosity relationship under these assumptions. (You may use the approximation that $T_{\mathrm{central}} - T_{\mathrm{surface}} = T_{\mathrm{central}}$)

d) Use the relations from b and c to predict the slope of the main sequence for "constant central temperature" stars (the observed value for real stars is between 7 and 8). Comment on this result and upon the importance of understanding nuclear burning to predict the slope of the main sequence.

Astro I – 3. Virial theorem

The virial theorem can be written as:

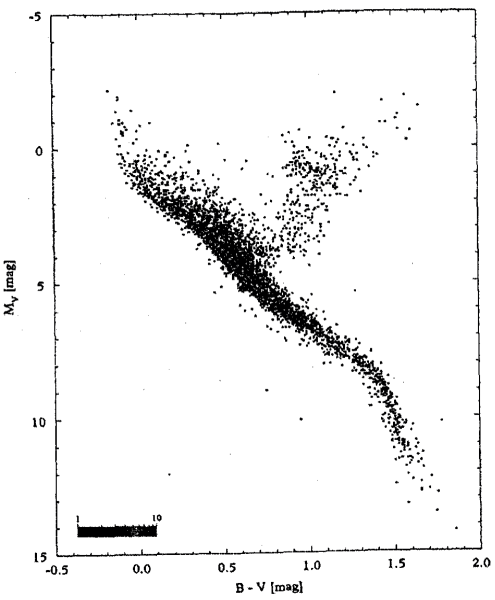
$$3\int P\,dV + \Omega = 0,$$

where P is the pressure and Ω is the gravitational potential energy. For an ideal, nonrelativistic gas this becomes $2K + \Omega = 0$.

a) Use the virial theorem to explain why adding significant energy to a star will cause it to cool.

b) We know a white dwarf will heat up if energy is added. How can this be consistent with the virial theorem? (Hint: the first term now has two components, one for the electrons and one for the ions)

Astro I – 4. Observational astronomy



a) The absolute v magnitude of the sun is about 4.8. Based on the Hipparcos H-R diagram (above), what is the B-V color of the sun?

b) Explain how to convert this B-V color into a temperature under the assumption that the sun is a blackbody.

c) What is the magnitude of a star with a B-V of 0.0? How many times more luminous than the sun is such a star?

d) If the sun is 6000K and has its spectral peak at 5500 angstroms, what is the temperature of a star with B-V of 0.0?

Astro I – 5. Nuclear Reactions

Nuclear reaction rates are proportional to

$$r \propto \left(\frac{8}{\mu\pi}\right)^{\frac{1}{2}} \frac{1}{(kT)^{3/2}} \int_0^\infty S(E) e^{-\frac{E}{kT}-\frac{b}{\sqrt{E}}} dE ,$$

where the *b* parameter is proportional to the product of the nuclear charges of the reactants and the square root of the reduced atomic mass $A=A_1A_2/(A_1+A_2)$

a) For non-resonant reaction rates, the S(E) can be treated as a constant, S_0, and the exponential approximated as a Gaussian. Explain where the two terms $e^{-E/kT}$ and $e^{-b/\mathrm{sqrt}(E)}$ come from. Sketch them separately and then sketch their product.

b) Show that the integrand has a maximum at $E_0 = (bkT/2)^{2/3}$

c) Helium burning is a two stage reaction, he first step of which is He^4+He^4=Be^8. It occurs at core temperatures about 10 times higher than for hydrogen fusion. How much higher in energy is the reaction peak? How is the peak otherwise changed?

d) The temperature dependence of the triple alpha reaction under discussion is T^{41}, much higher than the hydrogen burning sensitivity to T. Given your answer to c, how could this be true?

Numerical Constants:

Solar Mass (Msun):	1.989×10^{33} g
Solar Radius (Rsun):	6.96×10^{10} cm
Solar Luminosity:	3.847×10^{33} erg/s
Gravitational Constant (G)	6.6726×10^{-8} $cm^3/g/s^2$
Proton mass	1.6726×10^{-24} g = 938.27 MeV/c^2
Yield of p-p reactions (Q)	26.7 MeV = 4.28×10^{-5} ergs
Boltzmann constant	1.38×10^{-16} erg/K
Planck's Constant	6.626×10^{-27} erg-s
Electron mass	9.109×10^{-28} g
Proton mass	1.6726×10^{-24} g

NOTE: Due to the recent change of the graduate-level astronomy curriculum, the Astro II section of the 2007 Qualifier, which corresponded to the High-Energy Astrophysics class, will be replaced by a Galactic Dynamics section starting in 2008.

Astro II – 1. Wigner-Seitz Approximation

Consider a degenerate electron gas about an ion lattice.

(a) Consider a neutral, spherical cell of radius r_o about an ion of charge Z_e. Assume that the electrons are distributed uniformly and write down an expression for the charge q of the electrons within radius r.

(b) Calculate the potential energy $E_{e\text{-}e}$ of the electron-electron interactions (i.e., the energy it takes to assemble a uniform sphere of Z electrons).

(c) Calculate the potential energy $E_{e\text{-}i}$ of the electron-ion interactions.

(d) The total Coulomb energy of the cell is then $E_c = E_{e\text{-}e} + E_{e\text{-}i}$. Write down an expression for E_c as a function of Z and the electron density $n_e = 3Z/4\pi r_o^3$.

(e) The Coulomb correction to the ideal, degenerate electron gas pressure P_o is then $P_c = n_e^2 d(E_c/Z)/dn_e$. As electron density increases does $P/P_0 = (P_0 + P_c)/P_0$ increase, decrease, or stay the same (a) in the non-relativistic limit and (b) in the extreme relativistic limit?

Astro II – 2. White Dwarf Equilibrium and Stability

Consider a white dwarf of total energy $E=E_{int}+E_{grav}+E_{int}+E_{GR}$, where $E_{int} = AM\rho_c^{1/3}$ is the internal energy of an $n=3$ polytrope, $E_{grav} = -BM^{5/3}\rho_c^{1/3}$ is the Newtonial gravitational potential energy of an $n=3$ polytrope, $\Delta E_{int}=CM\rho_c^{-1/3}$ is the correction to the internal energy due to the electrons not being completely relativistic, $\Delta E_{GR}=-DM^{7/3}\rho_c^{2/3}$ is the correction to the gravitational potential energy due to general relativity, and M and ρ_c are the mass and central density, respectively. In cgs units, $A = 8.566*10^{14}(\mu_e/2)^{-4/3}$, $B = 4.264*10^{-8}$, $C = 4.950*10^{19}(\mu_e/2)^{-2/3}$, and $D = 4.549*10^{-36}$.

(a) Assume equilibrium and write down another relationship between A, B, C, D, M, and ρ_c.

(b) Ignore the correction terms in (a) and solve for M in solar masses. What is this mass?

(c) Do not ignore the correction terms and assume borderline instability to write down another relationship between A, B, C, D, M, and ρ_c.

(d) Substitute (a) into (c) and eliminate $AM\text{-}BM^{5/3}$. Substitute (b) and eliminate M. Solve for ρ_c in g/cm^3.

(e) Inverse ß-decay occurs if $\rho_c \geq 1.14 * 10^9$ g/cm^3 for iron white dwarfs, $3.90 * 10^{10}$ g/cm^3 for carbon white dwarfs, and $1.37 * 10^{11}$ g/cm^3 for helium white dwarfs. Does inverse ß-decay or GR-induced instability terminate the sequence of (a) iron, (b) carbon, and (c) helium white dwarfs?

$M_{sun} = 1.99 * 10^{33}$

Astro II – 3. Pulsar Magnetic Dipole Model

Consider a neutron star that rotates at a frequency Ω with a magnetic dipole moment m that is oriented at an angle α to the rotation axis.

(a) The magnitude of m is $B_pR^3/2$, where B_p is the magnetic field strength at the magnetic pole and R is the radius of the neutron star. Write m as the sum of three orthogonal vectors, one along the rotation axis that depends on $|\mathbf{m}|$ and α, and two that also depend on Ω and time t.

(b) Calculate the rate at which the neutron star loses rotational energy: $\dot{E} = -2|\dot{\mathbf{m}}|^2/3c^2$.

(c) The neutron star's rotational energy is $E=I\Omega^{2}/2$, where I is the moment of inertia. Take a derivative and substitute into (b) to eliminate $\dot{E}$.

(d) Write an expression for the characteristic age of the pulsar: $T=-\Omega_0/\dot{\Omega}_0$, where Ω_0 and $\dot{\Omega}_0$ are current values.

(e) Integrate (c) from Ω_i at $t=0$ to Ω_0 at $t=t_o$. Solve for t_o as a function of T, Ω_i, and Ω.

(f) For the Crab pulsar, T is measured to be 2556 years. Assume that $\Omega_i >> \Omega_0$ and calculate the pulsar's age. How accurate is your answer?

Astro II – 4. Neutron Star Accretion

Consider accretion onto a neutron star with a dipole magnetic field.

(a) The magnetic field will begin to dominate the flow of the in-falling gas at the Alfvén radius, where the energy density of the magnetic field becomes comparable to the kinetic energy density of the gas. Write down a simple expression for the energy density of the magnetic field in terms of field strength B and a simple expression for the kinetic energy density of the gas in terms of gas density ρ and speed v.

(b) For a dipole magnetic field, $B\approx\mu/r^{3}$, where μ is the magnetic moment. Assume that $v\approx v_{ff}$, the free-fall speed, and that $\rho\approx\dot{M}/4\pi v_{ff}r^{2}$, where $\dot{M}$ is the accretion rate. Write down a simple expression for v_{ff} in terms of the mass M of the neutron star and r. Substitute these expressions into (a) and solve for the Alfvén radius $r=r_A$.

(c) As the in-falling gas flows to the surface, gravitational potential energy is converted to kinetic energy and when it strikes the surface the kinetic energy is converted to luminosity. Write down a simple expression for L in terms of M, $\dot{M}$, and R. Substitute this expression into (b) and eliminate $\dot{M}$.

(d) Take $\mu\sim10^{30}$ cgs and L to be on the order of the Eddington luminosity. Ballpark r_A.

(e) For a dipole magnetic field, field lines are given by $\sin^{2}\theta/2=constant$. The in-falling gas is funneled to what fraction of the neutron star's surface?

$G = 6.67259*10^{-8}\ cm^{3}\ g^{-1}\ s^{-2}$
$M_{sun} = 1.99 * 10^{33}$

Astro II – 5. Aberration of Light

Consider the Lorentz transformation:

$$x'_{\parallel} = \gamma\,(x_{\parallel} - vt)$$
$$x'_{\perp} = x_{\perp}$$
$$t' = \gamma\,(t - vx_{\parallel}/c^2)$$

(a) Write down the velocity transformation.

(b) Let $\tan\theta' = u'_{\perp}/u'_{\parallel}$. Write down an expression for $\tan\theta'$ as a function of u, θ, and v (the aberration formula). Let $u=c$ and write down the aberration of light formula.

(c) HST images a star as it orbits at a speed of $v=7.56\ km/s$, completing an orbit every 97 minutes. By how many arcseconds does the position of the star appear to change as the angle between the telescope's pointing and motion changes from -90° to +90°? Ground-based telescope have to track at a rate of 900 arcsec/min to compensate for the earth's rotation. At what average rate does HST have to "track" to compensate for aberration of light?

(d) Suppose that you are traveling through space at 1% of the speed of light. All objects with 90° of your direction of motion (half of the sky) will appear to be concentrated within how many degrees of your direction of motion? What if you are traveling at $\gamma = 100$?

Appendix B: Physics Problem Books for the Qualifier

	A Guide to Physics Problems, Part 1	A Guide to Physics Problems, Part 2	Problems and Solutions on ____: Major American Universities PhD Qualifying Questions & Solutions	Princeton Problems in Physics with Solutions	Univ. of Chicago Graduate Problems in Physics with Solutions
Nickname(s) of Book:	'Red Book'	'Blue Book'	'China Book,' 'Lims'	'Princeton'	'Chicago,'
Author(s):	Sidney B. Cahn	Sidney B. Cahn	Yung-Kuo Lim	Nathan Newbury John Ruhl Suzanne Staggs Stephen Thorsett	Jeremiah Cronin David Greenberg Valentine Telegdi
Price (on Amazon):	$52.20	$46.16	$35-45 (depends on subject)	$33.25	$24.00
Subjects covered:	CM, EM, Relativity	QM, SM, Thermo.	ALL (One subject per book)	ALL	ALL
# Problems per subject:	50-70	50-70	300-400	10	40-45
Intricacy of Problems:	ok	fairly good	good	great	good
Thoroughness of solutions:	good	good	great	outstanding	poor
Additional comments:	Individual problems tend to be shorter and less in-depth than typical qualifier questions, each covering only one specific concept (in most cases). Useful appendices on physics concepts (i.e., a variational principle overview in the QM section). Problems are typically presented with light-hearted humor (including pictures).		Well-organized; divided into 'chapters' by subject. Solutions are presented directly after the problems, so no flipping vigorously between problem and solution sections as with all other books.	A diverse set of challenging problems. Downfall of book is low number of problems per subject. Major source of qualifier problems for many universities.	Better for some subjects than others (like SM, Thermo.) Note: Many past qualifier questions have come from this book.

Appendix C (Breakdown of Past Qualifier Problems)

Classical Mechanics *(chapters refer to Goldstein)*

Chapter 2 - Lagrange's Equations
CM-5 (2009), CM-3 (2006), CM-2 (2005), CM-4 (2005), CM-3 (may 2004), CM-4 (1999), CM-5 (1999)

Chapter 3 - Central Forces (orbits/scattering)
CM-4 (2007), CM-1 (2005), CM-3 (2005), CM-1 (2004), CM-1 (2003), CM-2 (2002), CM-3 (2001), CM-1 (2000), CM-5 (2000)

Chapter 4 - Kinematics of RBM/Coriolis effect
CM-2 (2003), CM-3 (2000)

Chapter 5 - Rigid Body EOM
CM-2 (2007)

Chapter 6 - Small Oscillations
CM-3 (2009), CM-5 (2006), CM-4 (2003), CM-3 (2002), CM-4 (2001), CM-3 (1999)

Chapter 8 - Hamilton's EOM
CM-5 (2007), CM-4 (2006), CM-3 (2003), CM-1 (1999)

Chapter 9 - Canonical Transformations
CM-4 (2009), CM-1 (2006), CM-2 (2006), CM-4 (2005), CM-5 (2005), CM-2 (2004), CM-5 (2004), CM-4 (2002), CM-5 (2002), CM-1 (2001), CM-5 (2001),

Chapter 10 - Hamilton-Jacobi Theory and Action Angle Variables
CM-2 (2009), CM-1 (2007), CM-5 (2003), CM-1 (2002), CM-2 (2001), CM-2 (1999),

Miscellaneous Topics
Noether's Theorem: CM-4 (2005), CM-2 (2000)
Dimensional Analysis: CM-4 (2004), CM-4 (2000)
Misc. Proofs: CM-3 (2007)
Scaling: CM-1 (2009)

Electromagnetic Theory 1 *(chapters refer to Jackson)*

Chapter 1 (Introduction)
EM-3 (2007), EM-4 (2007)

Chapter 2 (BVPs in electrostatics, method of images, corners)
EM-5 (2009), EM-1 (2009), EM-1 (2007), EM-5 (2007), EM-1 (2004), EM-5 (2004), EM-5 (2001), EM-5 (1999)

Chapter 3 (BVPs in electrostatics, Laplace, Legendre, Bessel)
EM-3 (2009), EM-3 (2006), EM-3 (2004), EM-1 (2003), EM-2 (2003), EM-4 (2003), EM-1 (2001), EM-2 (2000), EM-3 (1999)

Chapter 4 (Multipoles, Macroscopic media, Dielectrics)
EM-4 (2009), EM-2 (2006), EM-1 (2002), EM-2 (2002), EM-3 (2000), EM-4 (2000), EM-1 (1999)

Chapter 5 (Magnetostatics, Faraday)
EM-2 (2009), EM-2 (2007), EM-1 (2006), EM-4 (2006), EM-5 (2006), EM-4 (2004), EM-5 (2003), EM-3 (2002), EM-4 (2002), EM-5 (2002), EM-2 (2001), EM-3 (2001), EM-4 (2001), EM-1 (2000), EM-5 (2000), EM-2 (1999), EM-4 (1999)

Chapter 6 (Maxwell equations)
EM-3 (2003)

Electromagnetic Theory II *(chapters refer to Jackson (Rybicki))*

Chapter 6 (2) (Maxwell's equations)
EM2-5 winter (2004), EM2-2 (2002), EM2-3 (2002), EM2-2 (2001)

Chapter 7 (2, 8) (Plane EM Waves/Wave Propagation)
EM2-4 (2009), EM2-5 (2007), EM2-4 (2006), EM2-1 (2005), EM2-1 (2001), EM2-4 (2001)

Chapter 8 (Waveguides)
EM2-2 dec (2004), EM2-2 (2003)/EM2-1 (2002)

Chapter 9 (3, 10) (Radiating Systems, Multipole Fields, Radiation)
EM2-5 (2009), EM2-1 (2006), EM2-3 (2005), EM2-1 winter (2004), EM2-4 dec (2004), EM2-5 (2002)

Chapter 11 (4) (Special Theory of Relativity)
Kinematics – EM2-1 (2009), EM2-2 (2007), EM2-5 (2006), EM2-2 (2005), EM2-4 winter (2004), EM2-5 dec (2004), EM2-4 (2003), EM2-4 (2002)
Notation and 4-vectors - EM2-2 (2006), EM2-2 winter (2004), EM2-3 winter (2004), EM2-1 dec (2004), EM2-1 (2003), EM2-3 (2003), EM2-5 (2001)

Chapters 12-14 (3, 6) (Dynamics of Relativistic Particles/Transition Radiation/Radiation of Moving Charges)
EM2-3 (2009), EM2-2 (2009), EM2-4 (2007), EM2-3 (2006), EM2-3 dec (2004), EM2-5 (2003), EM2-3 (2001)

Quantum Mechanics 1 *(chapters refer to Sakurai)*

Chapter 1
Expectation values - QM-2 (2006)/QM-4 (1999)
Uncertainty relation - QM-5 (2003), QM-2 (2000)
Probability - QM-5 (2002)
Commutation relations - QM-1 (2009), QM-5 (2000)
Stern-Gerlach measurements – QM-1 (2007)

Chapter 2
Evolution in time - QM-4 (2003)
Heisenberg EOM - QM-2 (2009), QM-3 (2000)

Potentials - QM-3 (2009), QM-2 (2004), QM-4 (2004), QM-3 (2003) QM-1 (2002), QM-1 (2001), QM-2 (2001), QM-4 (2000)
SHO, coherent states – QM-1 (2007), QM-1 (2006), QM-3 (2004), QM-1 (2003), QM-4 (2002), QM-1 (2000)
Wave packets - QM-1 (1999)

Chapter 3
Advanced probability/Legendre - QM-5 (1999)
Ang. momenta - QM-5 (2009), QM-4 (2009), QM-3 (2004), QM-5 (2004), QM-2 (2003), QM-3 (2002), QM-3 (2001), QM-5 (2001), QM-2 (1999)
Bell's inequality - QM-5 (2006), QM-1 (2004)

Chapter 4
Parity/degeneracy - QM-2 (2002), QM-4 (2001)

Chapter 5/Appendix A
Hydrogen-atom - QM-4 (2006), QM-3 (1999)

Quantum Mechanics II *(chapters refer to Sakurai)*

Chapter 2/3
QM 1 problems/moving potentials - QM2-1 (2006), QM2-2 dec (2004), QM2-5 (2003), QM2-1 (2002)

Chapter 4
Symmetry, parity time reversal (chapter 4)
QM2-3 winter (2004), QM2-1 (2003), QM2-2 (2001)

Chapter 5
Degeneracy problem - QM2-4 (2009), QM2-2 (2005)
Time dependent perturbation – QM2-1 (2009), QM1-5 (2007), QM2-2 (2006), QM2-5 winter (2004), QM2-4 dec (2004), QM2-2 (2003), QM2-4 (2002)
Time independent perturbation - QM2-2 (2009), QM2-1 (2007), QM2-3 (2006), QM2-4 (2005), QM2-1 winter (2004), QM2-5 dec (2004), QM2-2 (2002), QM2-1 (2001),
Variational principle - QM2-2 (2007), QM2-3 dec (2004), QM2-4 (2003), QM2-4 (2001),

Chapter 6
Identical particles (helium) - QM2-5 (2006), QM2-2 winter (2004), QM2-3 (2002), QM2-3 (2001)
Non-helium identical particles - QM2-4 (2009)

Chapter 7
Born approximation - QM2-4 (2006), QM2-3 (2003), QM2-5 (2002), QM2-5 (2001)
Partial wave scattering - QM2-5 (2009), QM2-3 (2007), QM2-3 (2005), QM2-4 winter (2004), QM2-1 Dec (2004)
Metastability of bound states - QM2-3 (2009)

Miscellaneous

Density of states - QM2-5 (2005)
Transmission/Reflection Coefficient Calculations: QM2-5 (2007)

Statistical Mechanics *(chapters refer to Huang)*

Chapter 1 (laws of thermodynamics, VATUGSHP)
SM-3 (2009), SM-1 (2005), SM-5 may (2004)

Chapter 2 (apps of OD)
SM-4 may (2004), SM-4 (2003)

Chapter 6 (classical sta. mech.)
SM-2 (2005), SM-4 (2001)

Chapter 7 (canonical and grand canonical)
SM-3 (2007), SM-2 (2006), SM-4 (2006), SM-3 (2005), SM-3 may (2004), SM-1 (2003)/SM-1 (2002), SM-4 (2002), SM-5 (2002), SM-1 (2001), SM-3 (2001), SM-5 (2001), SM-1 (2000), SM-3 (2000), SM-5 (2000),

Chapter 8 (quantum stat. mech., also in chapters 11/12)
SM-1 (2009), *SM-2 (2007)*, SM-5 (2005), SM-1 may (2004), SM-3 (2003), SM-5 (2003), SM-2 (2002), SM-2 (2001), SM-4 (2000),

Chapter 10 (approximate methods, Ising also in chapter 14)
SM-3 (2002)

Miscellaneous
Adsorption - SM-1 (2006), SM-2 may (2004), SM-2 (2003), SM-2 (2000)
Ionization - SM-3 (2006)
Jellium problem - SM-5 (2006)
Rotations – SM-2 (2009), SM-1 (2007)
Critical points – SM-4 (2007)
Fluctuations – SM-4 (2009), SM-5 (2007)
Random spooky-but-trivial “entropic force” problem - SM-5 (2009)

Appendix D (Textbooks of the First-Year Courses)

Books most commonly used in your first year:

Classical Mechanics:

Title: Classical Mechanics
Author: Herbert Goldstein
Publisher: Addison Wesley; 3 edition (2002)
ISBN-13: 978-0201657029

Electromagnetic Theory I & II:

Title: Classical Electrodynamics
Author: John David Jackson
Publisher: Wiley; 3 Sub edition (1998)
ISBN-13: 978-0471309321

Suggested text for Electromagnetic Theory II:

Title: Radiative Processes in Astrophysics
Author: George B. Rybicki, Alan P. Lightman
Publisher: Addison Wesley; 2 edition (1994)
ISBN-13: 978-0201539295

Galactic Dynamics

Title: Galactic Astronomy
Author: James Binney, Michael Merrifield
Publisher: Princeton University Press (1998)
ISBN-13: 978-0691025650

Quantum Mechanics I & II:

Title: Modern Quantum Mechanics
Author: J. J. Sakurai
Publisher: Addison Wesley; 2 edition (1994)
ISBN-13: 978-0201539295

Statistical Mechanics

Title: Statistical Mechanics
Author: Kerson Huang
Publisher: Wiley; 2 edition (1987)
ISBN-13: 978-0471815181

-or-

Title: Statistical Mechanics
Author: R.K. Pathria
Publisher: Butterworth-Heinemann (1996)
ISBN-13: 978-0750624695

Stellar Astrophysics

Title: Principles of Stellar Evolution and Nucleosynthesis
Author: Donald D. Clayton
Publisher: University Of Chicago Press (1984)
ISBN-13: 978-0226109534

Title: Galactic Astronomy
Author: James Binney, Scott Tremaine
Publisher: Princeton University Press (1988)
ISBN-13: 978-0691084459

Suggested texts for Stellar Astrophysics:

Title: Stellar Interiors:
Physical Principles, Structure, and Evolution
Author: Carl J. Hansen, Steven D. Kawaler
Publisher: Springer; Second edition (2004)
ISBN-13: 978-0387200897

Title: Introduction to Modern Astrophysics
Author: Bradley W. Carroll, Dale A. Ostlie
Publisher: Benjamin Cummings; 2 edition (2006)
ISBN-13: 978-0805304022

NOTE: Many undergraduate-level textbooks will come to your rescue quite a lot this year, including Griffiths (EM, QM), Schroeder (SM), Marion & Thornton (CM), Fowles & Cassiday (CM), Taylor (CM), *Thermodynamics* (by Fermi).