ZapperZ's So You Want To Be A Physicist

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Please go to http://physicsandphysicists.blogspot.com/ or at http://www.physicsforums.com/ to find the writer of this essay. I welcome feedbacks. If you have recommended or used this guide, I would like to hear from you. If you think there are things are are missing, I also would like to hear from you.

Thank you.

Introduction: The motivation for creating the series

One of the most frequent questions we get in various physics forums and IRC physics channels (besides the annoying ”can anything travel faster than c?”) is the process and background of being a physics major. Often, we have students asking what are the requirements of obtaining a physics degree, and what can one do with such accomplishments.

I am hoping that, in a series of postings on this topic, we get to go over and demystify the whole process of what one can expect as a physics major in college, all the way to going through a Ph.D program, and even beyond that in the land of postdoctoral work and employment. This is not as easy as it sounds, especially considering the wide-ranging educational systems we have throughout the world. So in most cases, the perspective I will tend to have the most understanding with is the US educational system. This is where someone from another country can come in and contribute their experiences and wisdom.

What I hope to impart is not only what is known, as described in various brochures and guidelines from many schools, but also what is never told to the students. Most of these come from personal experience, things that I found myself saying ”Boy, I wish someone would have told me that earlier!”.

As usual, feedback and questions are welcomed as this series progresses. Who knows, maybe after this, I may finally be inclined to compile all this into the book that I’ve always wanted to write! :)

Part I: Early Physics Education in High schools

Most of us have various reasons or impetus for wanting to go into this profession. I sometime liken it to wanting to be a priest (I have a bad joke to accompany that, but I won’t say it) - the calling towards it that somehow can’t be ignored. We all know that being a physicist would not make us filthy rich, but there is somehow an intrinsic satisfaction working in this field.

In this part of the series, I’d like to start at the beginning. No, not during conception, or while one is still in the womb (although it isn’t too late to read to a fetus about Newton’s Laws of motion). The preparation one makes while still in high school before proceeding to college can be important. The most important of which, in my opinion, is one’s mastery of basic mathematics. Typically, by the time someone enters college, there should already be a good command of algebra, trigonometry and geometry. Taking intro physics without a good command of these three is a recipe for disaster. In many cases, one also needs at least a semester's worth of calculus if the intro physics class includes calculus.

Although this appears to be obvious, it isn't. In my brief teaching experience at the freshman level (1st year students in a university in the US), I often found that many students struggled with their physics homework not because they did not understand the physics, but they could not do the mathematics. Of course, they then blamed the difficulty of physics for this without realizing that the physics course itself was not to be blamed. Interestingly enough, we often encounter similar situation on our IRC channel. Students coming in with physics problems are often stuck more with the mathematics.

So, adequate preparations in mathematics at the high school level is crucial. In the US, one can still catch up on the necessary basic mathematics even after enrolling in a university by taking which ever mathematics courses that one needs. However, this will mean delaying other physics courses till one has the necessary mathematics skill.

Are high school physics classes necessary? Definitely. It is always advantageous to have a flavor of the simple ideas of physics before hand. In the US, there is such a thing as AP Physics, where high school students get advanced physics lessons almost at the college level of intro physics. This can do nothing but add to one's advantage.

Unfortunately, sometime these high school physics classes can backfire.

It is a sad reality that in many high school in the US, the physics classes are often taught badly, and often by someone without a physics degree. This has the negative effect of turning many students off this subject. Ask anyone who hates physics and chances are, they had a bad introduction to it in high school.

In Part 2, surviving the first year of college.

Part II: Surviving the First Year of College

This part covers the survival tips of the first two undergraduate years. So now you're in college, and you have every intention to be a physics major (actually, what I'm about to describe applies to anyone who is taking a physics class, not just for physics majors). In most US universities, as a freshman, you do not have a major-specific academic advisor, mainly because most freshmen do not have an officially-declared major. What you would probably get during your first week is a "generic" advising based on what you INTEND to go into. In all likelihood, assuming that you have all the necessary background, it is a safe bet that you would need the complete sequence of Calculus (typically a year, or 3 semesters worth). This would cover all the basic calculus and analytical geometry (level of Thomas-Finney), and towards the end of the sequence, may superficially cover more advanced topics such as vector calculus and partial differential equations. As a physics major, you will need more mathematics than this, and that includes a separate mathematics course in the two advanced topics that I have mentioned, and maybe even a course an complex analysis. These are the courses that you may have to take after you complete the calculus sequence (more discussion on mathematics in the next installment of this series).

The introduction physics courses can vary from school to school. Typically, the broad dichotomy would be Intro Physics with or without calculus. As a physics major, you would take the former. This means that, if you do not have any calculus background, you may have to delay your first physics class after you have at least completed the first semester of your calculus class (high-school students, take note of this!). The typical intro physics courses in US universities would be at the level of Halliday-Resnick. It is typically covered in 2 or 3 semesters and is intended to be a general survey of many different aspects of physics. These courses tend to be accompanied by laboratory work, which is intended to be an introduction to a systematic experimental study of various physics concepts.

I would like to expand on the importance of such laboratory work, mainly because for many students, this is looked upon as a waste of time, especially if the experiments and laboratory conditions are less than ideal. There are certain things that cannot be taught, but can only be acquired. These are what we call skills. The reason why one has to physically DO something during a laboratory session is to acquire such skills. This does not just mean physical skill, such as the ability to read an ammeter, to be able to perform a task with the least amount of errors, etc., but also mental skills, such as analytical ability to look at the object of the experiment and figuring out why certain things are done certain ways. This include the ability to critically analyze the experimental data to extract relevant information. Upon completion of such exercise, one must then be able to clearly explain in words and pictures (graphs) what one did, and the results. Again, such ability is important for obvious reasons and it is a skill that can't be taught. It can only be acquired through practice!

Note that what I have described above is not just applicable to physics majors. Such skills that can be acquired are important to anyone, regardless of one's major. In fact, I would make the assertion that acquiring such skills is MORE important for most students in a physics class than knowing the material. It is a fact that the majority of students in a physics class are not physics majors. Although the knowledge of physics is important as a foundation for other classes, for most of the students, the skills that can be acquired through physics classes and laboratories are the more valuable traits that they will carry with them throughout their academic life and beyond. The ability for critical analysis and knowing the reliability of data and results are important skills that are useful in all everyday life.

If you are an undergraduate in a US university, there is no excuse for not enrolling yourself in The Society of Physics Students (SPS). This organization is open to all students, not just physics majors. As part of your membership dues, you are a year subscription to Physics Today, a journal that practically all physicists read and contains timely information on the world of physics and physicists. You will also get newsletter and information specifically targeted for undergraduates like you, and also entitles you later on for significant discounts and even free registrations to attend various physics conferences. In other words, if you have even half a brain, enroll in this! The benefits are just too great to not to. Go to the physics department at your school and ask if they have a chapter of the SPS there. You can enroll via your school's chapter. If there isn't any, go to the SPS website at

http://www.aip.org/education/sps/index.html

and you may enroll there as an individual member. It is NEVER too early to be a member, so do it as soon as you are settled. If you are not in a US university, you may still subscribe to Physics Today by going to their website at

http://www.aip.org/pt/

Throughout your first 2 years, the BEST thing you can do for yourself is to get excellent grades. This, I'm sure, goes without saying, but you have to realize that typically, these are the easiest and the most important courses you will see in your undergraduate years. They are the foundation that you will build on for your other courses, and they are the ones you have a better chance of achieving the highest grades. Do not be discouraged if you feel that at this stage, you are one of the many anonymous "numbers" in a large class. Most classes at this level tend to be huge and it isn’t easy to distinguish oneself from the crowd (you will have plenty of opportunities to distinguish yourself later on). But do not let this stop you from seeing the instructor during his/her office hours, or using the Teaching Assistants if you need help. They have been PAID to do just that!

In the next installment, we will discuss the transition between the intro classes and the more advanced undergraduate classes, and your first tentative steps towards distinguishing yourself from other students.

Part III: Mathematical Preparations

In most universities in the US, a student must have a declared major by the end of his or her second year. So this is an important transition - making the commitment in a particular area of study. By now, if you have followed the first two chapters of this series, you would have been aware of the necessary background to pursue your academic life in the physical sciences or engineering. All the discussion that we have had so far has been ”generic” to a large variety of field of studies. However, at this point, this discussion will be more specific towards being a physics major.

The end of your second year marks the beginning of a more advanced undergraduate physics courses. You will probably no longer be in the same classroom as other majors, and most of your classes will comprise of only physics majors. This part of the series will focus on additional preparation you should have to be able to sail through your advanced undergraduate physics courses.

It was alluded to in a previous posting on here of having sufficient mathematical background. It has often been said that a physics major sometime needs more mathematics than even a mathematics major. Mathematics is viewed as a ”tool” that physicists use in describing and analyzing physical phenomena. So one just never know what tools are needed for which job. This means that a physics major must have a wide ranging knowledge of different areas of mathematics, from differential equations, linear algebra, integral transforms, vector calculus, special functions, etc. These are the mathematics a physics major will encounter in courses in classical mechanics, electromagnetic fields, and quantum mechanics. Unfortunately, most physics majors do not have the inclination, nor the time, to be able to take all the necessary mathematics classes. What typically happens is that they learn the mathematics at the same time they are learning the physics. This is an unfortunate way to learn the material, because more often than not, the mathematics gets in the way of understanding the physics. It is hard enough to learn the physics, but having to also learn the mathematics simultaneously makes the problem rather daunting.

Many physics departments are aware of such problems, and one of the remedies is to offer a course in mathematical physics. This is typically a 1 year, 2-semester course covering a wide range of mathematics that a physics major will need. The purpose of such a course is to give a brief introduction to various areas of mathematics, not from the point of view of rigorous proofs and derivations, but from the point of view of how to use them effectively and correctly, especially when applied to actual physics problems. If there is such a course at your school, I highly recommend that you enroll for it as soon as you can, especially before you need them in your physics classes. That last part, however, can be a problem. I have observed that in many schools, a mathematical physics course tends to be offered late in undergraduate program, or even as a graduate course. This, of course, does no good for someone wanting to learn the mathematics before one needs it. If this is the case, I would strongly suggest that you purchase this text: ”Mathematical Methods in the Physical Science” by Mary Boas (Wiley). I have been recommending (threatening?) this text to several people. This book is meant for someone to start using at the end of the 2nd year, and can be used as a self-study. It doesn’t require the mathematical sophistication that other similar books require, such as Arfken. Furthermore, the Students Solution Manual that supplements the text is a valuable book to have since it shows the details of solving a few of the problems. I would recommend getting both books without the slightest hesitation.

Knowledge of computers is almost a ”given” nowadays. However, in physics, this goes a step further. No matter which area of physics you intend to go into, you MUST know (i) how to program and (ii) how to do numerical analysis. The first part is automatic. Most schools require at least a class in computer programming, using a favorite computer language. Most the field of physics, FORTRAN is still in wide usage, C is a language that is gaining in popularity, and C++ is beginning to take hold. I suggest that the minimum number of programming language you should at least have a working knowledge of is 2: Fortran and C.

The 2nd part of programming, numerical analysis, isn’t as automatic. This is the part most computer science majors do not do, but where most physics, mathematics, and engineering majors, have to do. In many instances, the mathematics that describe a physical system is not solvable analytically. This may be in the form of large matrices, non-linear differential equations, etc. In those cases, one can only find values out of the mathematics by solving them numerically. Learning the mathematics of numerical analysis is an extremely valuable skill for your academic knowledge, and even for your ”marketability” to be employed. Do not be surprised if a few of your courses require a class project involving numerical computing of physical systems. Whether you intend to be an experimentalist or a theorist, you will need to know how to perform numerical computation.

To give students such skill, most schools offer a specific course in computational physics (in some cases, this is a specific area of study in itself at the graduate level). However, sometime such a course is not offered by the physics department, but rather by either the mathematics department (as a numerical analysis course) or the engineering department. Either way, you need to make sure you get a formal education in one of these, especially if it isn’t part of a required set of classes that you have to take. In the next installment of this series, we will discuss on the most important people in your life as a physics major: your adviser, your instructors, and your teaching/laboratory assistants.

Part IV: The Life of a Physics Major

So far, I have covered what I believe a student needs all the way to the end of the 2nd year of studies. In most schools in the US, an undergraduate must have a declared major by the end of the 2nd year (if not sooner). So by now, you should already be officially a physics major. Hopefully, by now, you would have made acquaintances with other physics majors and know who are in the same year group as you. This is important because chances are, you may want to find someone to discuss homework problems, etc. This is where having a local chapter of the Society of Physics Students (SPS) at your school can be useful. You get to meet other physics majors, and also talk to the more senior students who can give you a better idea of what to expect (or which professor to avoid in certain classes). You should also keep in mind that there is a good chance that these are probably the same people who might continue on in this profession, and that the friendship you are establishing might someday turn into a valuable point of contact in your professional career. Never underestimate the value of personal contacts.

The transition from the 2nd year into the 3rd year of college can mean smaller classes and more advanced subjects. This is where you start studying the ”meat” of a physics program -

what I would call the 3 foundations of physics: classical mechanics, electromagnetic fields, and quantum mechanics. These are taught in separate courses, typically over 2 semesters each. Typical textbooks for each course are: classical mechanics - Marion or Symon; E&M: Griffith, Reitz/Milford/Christy; QM: Griffith, Liboff. Now pay attention to this: ALL other physics subjects BUILD on the foundation laid by these three courses. The importance of these subjects cannot be overemphasized. In fact, if you are able to do it, you may even want to consider lowering your class load for 1 or 2 semesters while you're taking one or more of these classes just so you can devote extra time to them. An E&M class, for example, can easily suck in a lot of time to understand and the homework problem can take a long time to finish. If you can afford it, do not hesitate to buy one of those books that have sample questions and worked out answers (Schaum and Rhea have a series of those). Now don't cheat! Use them as guides and extra practice exercises to make sure you understand the material.

If you are in a school with a small student population, chances are that the faculty would already know you either by sight or by name. If not, this is where you have to start distinguishing yourself. Talk to your instructors if you do not understand something, that is why they have office hours. Introduce yourself so that they know your name. By the middle of your 3rd year, you should have enough physics knowledge that you might be somewhat useful to do some work. Ask around if there are any research project or groups that you can work in, or find a professor that might be interested in giving you a simple project for you to work on. This is especially relevant in your 4th and final year where most schools have a senior research class available. Start attending your department's weekly seminar/colloquium. Most of these may be way over your head, but they tend to cover a lot of research front areas of physics. You might also get some flavor if some of these research work are either done, or of some interest, at your school. The point here is that you need to start distinguishing yourself slowly by this time. The faculty in your department should not just see you during class time.

Your contact with our academic adviser may depend on you and your needs. Most of the time, you only need to see him/her when you have to decide on what classes you need to take for the next academic term. But if you want to discuss with someone about your academic goals and what advanced level classes to take if you want to follow a certain path, he/she should also be someone you should consider. Make full use of the responsibility that they have been given. Now, in many schools, you are also given the freedom to choose your own academic adviser. Check with the policy of your department. If that is the case, you can certainly ask if a faculty member that you prefer can in fact become your undergraduate adviser. Again, this option may not be available in all schools, especially for smaller ones. Many undergraduates tend to stick to the person they were assigned to when they declared their major. The role of an academic adviser at this level isn't as crucial under ordinary circumstances as when you get into graduate school.

The next part of this essay applies only to US universities and to US citizens/permanent residents. If your school lacks the research work that are of any interest to you, or if you want additional experience over the summer holidays, then you may want to consider applying for the summer internship programs provided by the US Dept. of Energy. This provides an excellent opportunity for you to work at a world-renowned facility with practicing physicists. You may find the necessary information at the DOE website below:

http://www.scied.science.doe.gov/scied/sci_ed.htm

Keep in mind that competition for the internship is very intense. So, apply early!

In the next installment of this series, we address the final year of your undergraduate life, and the looming reality of either joining the rat race, or continuing on to graduate school.

Part V: Applying for Graduate School

We have now reached the final year of your undergraduate program. By now, you would have gone through courses in the fundamental pillars of physics (Classical mechanics, Quantum mechanics, and E&M), and even courses in Thermodynamics/Statistical Physics. Academically, this is where you start taking more advanced courses, even some graduate level courses. There are plenty of options, depending on where you go to school, how large your physics department is, etc. The choices can range from a class in Solid State Physics, Particle Physics, advanced laboratory work, etc. If you already have a clear set of interest and know what area of physics you would like to end up in, then this is where you want to try to enroll in a class in that area. But even if you don't know for sure yet (and this tends to be the case for most students), it is still valuable to enroll in one of these "specialized" area of physics, even if you may not eventually go into that field.

The start of your senior year requires that you do some serious thought on what you wish to do upon graduation. Most physics majors will go on to graduate school with the hope of obtaining their doctorate. So in this part of the series, we will concentrate on the application process of going to graduate school. If this is the path you intend to take, then you need to prepare yourself in a number of ways:

1. Prepare to take your Graduate Record Examination (GRE). This should include both the GRE General and GRE Subject Test. While the GRE scores may not be required for admission application in many schools, they are usually required if you are seeking any form of assistantship. So it is best if you already have the test scores.

2. Apply to graduate schools EARLY! If you intend to enroll in the Fall, you should have ALL your applications in by December of the previous year, especially if you are seeking assistantship. In many highly competitive schools, your applications may need to be in even earlier. It is NEVER too early.

3. Unless you have a 4.0 GPA, have outstanding letters of recommendation, and the son of the President of the United States, you have some uncertainty if your first choice of schools will accept you. It is ALWAYS recommended that you group the schools you are applying to into 3 categories: (i) Top Tier schools that you know are very difficult to get in (ii) Middle tier schools that you may have a chance to get in and (iii) lower tier schools that you think you can definitely get in. Note that these does not have any reflection on the QUALITY of instructions/programs at each school. In many instances, it is only the "perceived" prestige that makes one school more "desirable" than the other.

4. Do as much research on each school that you are applying. If you know of some program or research area that a school is good in that you are also interested in, then look it up and try to find the latest publications in physics journals. Your admission application usually requires that you write an essay regarding your aims, ambitions, and why you would want to study there. So it is always good to be specific, and not just give some generic description. Mention things specific to that school and that physics program and why you want to be involved in that. It is extremely important if you can also show a previous interest or work in a similar area. This will tell the admission officer that you are a candidate that can be beneficial to them. Note that saying such a thing in your application typically does NOT commit you to that particular area of physics. You can still change your mind later on if you wish. So don't hold back on the enthusiasm.

5. This last part is a bit dicey, since the situation can either turn out very positive, or very bad. If you feel confident enough in your ability, you may want to contact directly a faculty member of school that you would like to attend. Obviously, this would be a school that is highly competitive. You want to do this in cases where you think a direct communication may enhance your chances - so don't do this if you think your contact may backfire. The best way to do this is to see if any of the faculty member of your undergraduate institution know of anyone there personally. It is always best to have such recommendation. If you do decide on such contact, tell the person why, your interest, and that you would be interested in working in his/her research group, etc.

In the next installment, I will try to describe what you can expect graduate school to be BEFORE you get there.

Part VI: What to Expect from Graduate School Before You Get There

We are still discussing the final year of your undergraduate program where you are in the midst of applying to graduate schools. In Part 5, I mentioned the word "assistantship" several times, and it is important that you understand what this is, and why you should apply for it. So this part of the series will focus solely on the issue of assistantship. Take note that the kind of assistantship that I will be discussing applies only to US universities. However, ALL incoming graduate students, regardless of whether they are US citizens or not, qualify for these assistantships. So a *qualified* student from another country can certainly apply for one of these. However, as in many cases, there could be exceptions to this, especially if the source of the money comes with restrictions (such as research funded by the US Department of Defense, which would require US citizenship and/or background security checks).

There are two forms of assistantships: (i) teaching assistantships (TA) and (ii) research assistantships (RA). No matter which form of assistantships that is being offered, typically what is involved is a complete tuition/fees waiver, and a stipend. What this means is that your schooling tuition and fees are being paid for by your department, and you will also receive a paycheck (stipend) for your services. The amount of your stipend depends entirely on your school. So this award is certainly significant especially since top tier schools can have outrageously high tuition and fees. So now, what are the differences between the two types of assistantships?

In practically all physics departments, and especially so at large schools, they need the manpower from the physics graduate students to either conduct tutorial/discussion sections, run physics laboratories, and/or do homework/exam grading of lower-level physics courses. Therefore, they award a number of TA each year or semester. So you become part of the department's manpower to help the various faculty members in various physics courses.

As an incoming physics students, TA'ship is the one you most likely have a chance to get. However, your chances of getting one depends on the number applying for it. Each school tends to already reserve TA'ships for they graduate students who have already earned one the previous year. So whatever is left to fulfill their needs/budget is the one being offered to the new incoming pool of applicants. So certainly, competition for this award can be intense. Take note also that in many schools, especially the ones that care about the quality of their instructions, you may need to prove your ability to communicate clearly in English, both written and verbal. Since you will be dealing, often directly, with undergraduate students taking those various physics classes, it is important that you are able to communicate with them. So if you are from a non-English speaking background, you will need a good TOEFL scores, and other supporting evidence, to bolster your chances.

The RA’ship, on the other hand, isn’t usually available for new, incoming graduate students. An RA is a research position, and it is awarded by individual faculty members based on the research grant that he/she has obtained. Most faculty members do not award RA’ships to a graduate student until he/she has at least passed the department’s qualifying exam (more on what this exam is in a future installment of this series). For most graduate students, the RA’ship is a way to do one’s doctoral research work while being paid for it. So your RA work also becomes your doctoral dissertation, meaning that you’d better be working in the area of physics that you want to specialize in.

Depending on what field of physics you want to go into, and whether it is theoretical or experimental, you may end up receiving a TA’ship throughout your graduate career, especially if your supervisor has no research grants to hire you. Experimentalists tend to have higher chances of getting an RA’ship, simply due to the nature of the work.

The point that I’m trying to get across is that depending on your ability and your GPA, graduate school may not cost you an arm and a leg. It’s true that many US universities are extremely costly. However, a physics graduate student has a lot more options in finding ways to reduce such cost. Schools such as Stanford, for instance, automatically assumes that you will require some form of assistantship when you apply to the physics graduate program. In fact, practically all of their graduate students are on some form of assistantships/scholarships. However, due to intense competition for the limited funds, you need to do all you can to make yourself stand out. Hopefully, you have done that during your undergraduate program, and have sent in your applications early.

Part VII: The US Graduate School System

We are still stuck in the discussion of your fourth and final year of college. This time, I feel that a clearly explanation of the US graduate school system is warranted, especially to others from the rest of the world who intend to continue their graduate education in the US. This is because there is often a great deal of confusion, from the conversation that I’ve had, regarding what is required to apply for a Ph.D program in physics in the US.

The broad dichotomy of higher education in physics in US institutions can be lumped into (i) undergraduate education and (ii) graduate education. When you have completed your physics undergraduate education, you typically earn a degree of Bachelor of Science (B.Sc). (There are some schools that actually award a Bachelor of Arts in physics, but that’s a different path that we won’t discuss here.) Now this is what we refer to as your undergraduate degree.

If you do decide to go on to graduate school, then the two different physics degrees available to you are the Masters of Science (M.Sc) and Doctor of Philosophy (Ph.D).

Now the next step is where US institutions differ from many educational system throughout the world. If you intend to pursue a Doctorate degree in physics, you do NOT need to first obtain a M.Sc. degree. Practically all of the universities in the US that I’m aware of require that you have an undergraduate degree to apply to a Ph.D program. Your undergraduate degree and transcripts of your undergraduate class grades are the ones being used to evaluate your candidacy. This is different from, let’s say, the UK system, where you first pursue your M.Sc, and then after completing that, go on with your Ph.D. In US institutions, if you are pursuing your Ph.D, you can get your M.Sc ”along the way”, since at some point, you would have fulfill the requirements for a M.Sc degree. In fact, I know of a few people who didn’t even bother declaring for their M.Sc degrees. So you will see some people with academic credentials as ”B.Sc in physics from so-and-so; Ph.D in physics from so-and-so”, with the M.Sc degree missing.

These differences have created a sometime confusing discussion from people intending to enroll in the graduate program in the US. The first confusion comes in when they check the average length of time to complete a physics Ph.D. Most are shock that the average length of time to complete a Ph.D in the US is 5 1/2 to 6 years. I was told that it takes an average of 3 years in the UK. However, if you consider what I have mentioned earlier, the length of time for a Ph.D is taken from the enrollment into the program by someone with a B.Sc degree, whereas the UK number is taken from the start of the program after someone has obtained a M.Sc. or equivalent. It takes an average of about 2 years to complete a physics M.Sc in the UK, I think. So now there is a explanation of the apparent discrepancy between the length of time. The total length of time to obtain a Ph.D after someone has a B.Sc degree is still roughly similar in both educational systems.

The second, of course, is the idea that one must have a M.Sc degree before applying for a Ph.D degree. Again, if one were to browse through the requirement for acceptance into a Ph.D program at a US institution, one will see that the major requirement is an undergraduate degree. I know of many international students who either (i) stayed in their home countries to get their M.Sc and then apply for a Ph.D program in the US, or (ii) apply explicitly for a M.Sc program in the US even though their goals are to obtain a Ph.D, because they assume that one must obtain a M.Sc first, before going on to a Ph.D program. This can actually create additional annoying problems, because one sometime has to REAPPLY for enrollment into the Ph.D program (this means you may have to pay again the application fee, fill in application forms, etc...) They also must apply for a change of status on their visas, because they are now pursuing a different degree.... In other words, these are all messes and annoyances that could have been avoided had one understood the graduate school system.

So remember: check the requirements for admission into a Ph.D program for a US institution. A B.Sc degree is required, not a M.Sc. So if you intend to pursue a Ph.D, apply directly for a Ph.D program, using your B.Sc. degree.

Part VIII: Alternative Careers for a Physics Grad

We are still discussing the final year of your undergraduate education. So far, we have covered what you need to consider if you want to go on to graduate school and prepare yourself as best as you can for that part of your journey. This is the "traditional" path that many physics students follow. However, this isn’t the only path one can take with an undergraduate physics degree. Many physics degree holder do not continue to pursue a graduate degree in physics. So in this part of our series, I will discuss this aspect of an education or career beyond the traditional physics path.

If you have followed the series so far, you would have noticed that very early on, I emphasized one very important thing: the acquiring of a range of skills during your undergraduate years. This includes everything from computer programming skills to experimental skills. This is extremely important for any students, but especially if you end your physics education upon completion of your undergraduate degree. If you decide to pursue employment, your employability depends very much of what you can do. Let’s face it, not many employers are looking for someone who can ”do physics”. There are, however, employers who would like someone who can analyze numerical models and maybe write codes, or maybe someone who can work in an electronics industry doing thin film fabrication, etc. You will be surprised that some of the things you accidentally picked up in an advanced physics lab might be the very thing that gets you the job.

One of the most popular path that physics graduates take at this point is to go into teaching at high schools. Most who intend to pursue this line of work usually were enrolled in a simultaneous education program while they were pursuing their undergraduate degree. That way, by the time one obtain one’s physics degree, one is also qualified to teach high schools. However, there are many graduates who obtain their teaching certificates after the fact. So it is never too late to decide that this is the profession you want. Keep in mind that different states in the US may have their own requirements with regards to teaching credentials. Some may even allow you to start teaching while you are in the process of getting your certification. So this advice comes with plenty of caveat.

One of the growing options for physics degree holders is to go into a graduate program in a different field of studies. There is now a clear, growing need for physics degree holders to go into law. With the high demand for patent lawyers (not to mention very high salary), there are many physics graduates who are pursuing their law degrees.

Another popular career change is to go into medical schools. This is very common to many students especially if they intend to go into medical physics research (note that one doesn’t need to go into medical school to major in medical physics). Again, there is a growing number of physics degree holders who are making use of their physics degree in this field. One of the other ”untraditional” avenue being adopted by physics graduates is to go into either journalism, or writing. There are schools now offering cross-disciplinary programs in which students majoring in an areas of science or engineering can also augment their education with either a minor or even a double major in such untraditional subjects. Most are training either to go into mass media (science reporter), or even politics as assistants to various representatives in Congress. There clearly is a demand for scientists who can write and speak very well to the public, and programs such as these aim to produce such people.

A growing number of physics degree holders (with B.Sc, M.Sc., and Ph.D.) are now opting to go into industries and become "engineers". This is especially true for the electronics/semiconductor industries that have hired many physics degree holder. It is often confusing and misleading to many because these people often hold the title of "engineers", but with a physics degree. Industrial physicist is definitely a viable option for many as shown in the latest AIP job statistics:

http://www.aip.org/statistics/

There are many other avenues one can pursue with a physics degree. I have only listed just a few. However, in every single one of these, the preparation is still the same. One must have as wide as an experience as possible as an undergraduate. This will allow for the possibility that something one did might end up being the useful skill that one needs for a certain line of career.

In the next installment of this series, we will finally graduate out of our undergraduate years and go into the dreaded first year as a graduate student and the nightmare of facing with the qualifying exam!

Part VIIIa: Entering Physics Graduate School From Another Major

I have decided to tackle this issue because it became a very common question in many physics forums. Can someone, without a degree in physics, get accepted and succeed in physics graduate school all the way to obtaining a Ph.D?

Obviously, this question cannot be answered easily, because it depends on (i) your major (ii) what physics and mathematics classes you took as an undergraduate. Students majoring in, say electrical engineering, engineering mechanics, mathematics, applied mathematics, etc. will have an easier path to going into physics than, say, student who majored in economics, musics, etc., mainly because of many overlap in courses that one took as an undergraduate.

Still, I think that there is a concrete way to determine how well-prepared you are in going into a physics graduate program. This is something you can do yourself as a first level of self-evaluation on whether you are well-equipped to enter such program, or if you lack some necessary knowledge to complete it successfully.

1. Get a copy of a GRE Physics Subject test. Now try to do the test yourself. If you did not score 75% or better, you lack the necessary preparation to go into a physics graduate school

2. If you have a school that you already have in mind on where you might want to apply to, get a copy of the previous-year's qualifying exams (more on the qualifying exams in Part IX of this essay). You don't even have to actually do the exam. Just read it, and see if you actually understand what it is asking, and what you will need to be able to solve it. If you find that there are questions that go over your head, and you don't know where to look for the way to start solving it, you immediately lack the necessary preparation to go into a physics graduate school.

These are concrete, self-evaluation that you can test on yourself. The GRE self-test should test a wide variety of physics knowledge that a typical physics undergraduate should have by the time he/she graduates. This allows you to compare your knowledge to such group of student. 75th percentile score isn't that high, but in this self-test, you get to use as much time as you need, and may even need to refer to physics text books to help you with your test (something you can't do in an actual GRE test). I consider knowing where to look for help as an indication that a student isn't clueless.

The qualifying exam self-test is more school-specific. This is the standard of knowledge that a particular school would want their graduate candidates to have, so the questions tend to be more difficult, and it isn't a multiple choice exam. Here, I merely wanted you to see if you can actually understand what is being asked, and then to know a way to solve it, without actually having to solve it. Most physics students can understanding the question, and have an idea on how to solve it. The process of solving the question itself may not be trivial (usually, it isn't!), but knowing a way to do it is a major indication that a student has the necessary knowledge. So if you encounter anything here that makes no sense to you, and you also are clueless in figuring out a way to solve it, then you lack the necessary preparation.

The thing here is that, depending on where you intend on applying and your educational background, getting accepted into a physics graduate program isn't the biggest issue, especially if you're paying the full tuition and fees yourself. With an engineering degree/computer science/math degree and a GAP of 3.0 or better, you can find schools that might accept you into their program. The question is, can you survive in the program and ultimately, get to your goal of receiving your Ph.D? It would be a waste of time (and financial resources if you're paying full fare) if you get snagged in the qualifying exams because you were not sufficiently prepared.

If you don't think you are sufficiently prepared, you need to evaluate on whether you should apply to a school, and then spend maybe a year, or even two, in advanced undergraduate courses to not only get you up-to-speed, but also to prepare you for the qualifying exams. Many schools will allow you to do this. This evaluation will depend on your current educational background. I would say that engineering and math majors will have the advantage here on not needing way too many courses to get them up and running. If you come from a non-science, non-technical background, you may want to consider how far up a hole you're willing to climb to achieve your goal.

Using the two self-tests that I mentioned above will give you a concrete evaluation of your knowledge to survive a physics graduate program.

Part IX: First years of Graduate School from Being a TA to the Graduate Exams

You are now entering your first year of graduate school. In terms of academic aspect, you will have a set of required courses that you must take. Typically, these courses would be advanced classical mechanics (at the level of Goldstein), advanced QM (at the level of Merzbacher and Sakurai), and advanced E&M (at the level of Jackson or Landau-Lifschitz). Some or all of these classes may cover more than a semester or quarter. No matter what you intend to specialize in later on in your graduate studies, these are courses that all physics graduate students must take. So plan on spending maybe the first 2 years of your graduate life taking your required and optional classes. This should also give you the opportunity to get to know the various faculty members, the specific types of research work being done at the school, the faculty members who has the money to support graduate research assistants, people you want to avoid like a plague, etc. These are all intangibles that you can only find out once you are there and experiencing the system.

Take note that in the majority of graduate programs, you do not have to enroll in as many credits hours per semester as what you were required as an undergraduate. Most schools have a lower minimum credit hours for graduate students than undergraduates, some even have no minimum. So you can take one, two, or even just three classes per semester. This is especially helpful if you are also a teaching assistant and have to put in some hours per week doing your responsibility. However, keep in mind also that in most schools, graduate students are expected to attain higher grades than undergraduates in all their classes. Typically, anything below a B is a failure (this varies from school to school, so double check!). So you cannot get below some minimum grades (not just an F) to maintain a passing mark.

If you are lucky enough to receive a teaching assistantship, then you will be assign duties with certain faculty members. This may include running a physics undergraduate laboratories, grading homework/tests, or even conducting a discussion/tutorial session. Many graduate students tend to look at these as a chore, but permit me to give you one important advice. You have NOT understood a material UNTIL you are able to teach it effectively to another person. I will say without hesitation that my experience in being a TA has been nothing but a completely wonderful learning experience FOR ME. You quickly realize that if you want to do a good job (rather than a mediocre one), you have to be meticulous in how you present things to the students who are about to learn the material. Even grading homework solutions can be a challenge sometime, especially when you have a bunch of very intelligent students who can sometime offer a rather different approach to answering a question. My philosophy in approaching my TA duties had always been ”if I have to to this, I might as well do it as well as I can”. I think if you have pride in yourself and your ability, you’d never want to produce a half-baked piece of work. This, I believe, is the only way to not only fulfill your responsibility for what they hire you for, but for you to also get as much out of it as possible. Besides, you CAN add this to your resume later on!

But now, we come to the BIG MONSTER that is looming in your future : the dreaded qualifying examination.

First of all, what the hell is it? It is an exam given by the physics department of your school, to test if you have the basic, fundamental physics knowledge to be able to complete the program. So these tests are highly ”school-dependent”, and thus, can vary in scope, nature, procedure, length, etc. Typically, the exam is offered once a year, and a phd candidate has the opportunity to pass it by the end of his/her 2nd year of graduate studies. Failure to pass it by then will prevent the candidate from continuing (a polite way of saying ”You have to leave and can’t come back!”). This is why many research groups would not want you working for them till you pass this thing, because they can’t be sure that you won’t just disappear.

Secondly, what is involved in such an exam? Again, this varies quite a bit from school to school. Based on my observation, the qualifying exam can go from one big exam in a single day, to an exam spread over 2 days, to something that goes on for 5 consecutive days! I have seen schools having separate days for different subject areas in physics: Day One - Classical Mechanics, Day Two - E&M, Day Three - QM, etc.. I’ve seen graduate exams in which if you pass CM and E&M, but fail QM that year, then the following year, you only need to retake the QM part of the exam, while others make you retake the whole thing. And get this, in some schools, the written part is only HALF of the exam - there could be an oral part of the qualifying exam where you are asked various questions and have to respond verbally and work out your answer on the board. I’ve seen schools that use such oral exams for students with borderline pass/fail results to see if they have a higher ability than what is reflected in their exam scores.

Thirdly, what is covered in the exam? A simple answer: everything that was taught to you at the undergraduate level in a typical physics curriculum. Because of this, it is often that a graduate student enroll in an advanced undergraduate class or two during their 1st year of graduate studies just to get up to speed with areas that he/she is weak in. So you do have a limited time to shore up your weak points. In some schools, especially the highly competitive ones, even the 1st year graduate material is included in the qualifying exam. So again, the scope and difficulties of the exam content can vary school to school. But what is common is that you MUST know your undergraduate CM, E&M, and QM without fail! This is a given. You should also know very well Thermodynamics and Statistical Mechanics. Some exams allow you the option to choose the more specific areas such as particle physics, solid state physics, nuclear physics, atomic physics, etc. I have also seen a qualifying exam that, essentially, tests you on your ”historical” knowledge. A question lists a number of important experiments in physics, and you are asked to pick... oh, 3 or 4, and write down what it is, and why it was such an important experiment. So the moral of the story is, almost everything and the kitchen sink, can be in one of these exams.

Fourth, how does one prepare for it? As I’ve said above, some students retake a few undergraduate classes as preparation. However, the most effective way for you to prepare for such an exam at your particular school is to ask for copies of previous qualifying exams. The department usually keeps a record of old exams (if they don’t, they should!). If not, ask the elder graduate students. Unless they take back the exam questions, the more advanced graduate students should have copies of the exam they sat for. Now work through them. It may be useful to work in groups so that you all can agree on what the correct solution is. There may be also books that publish old qualifying exam questions - I’ve seen one for Princeton (with answers!). What this will do is give you a flavor of the kinds of questions and the level of knowledge that you are expected to have. But here’s a warning: qualifying exam committee changes every year. So do NOT be surprised if you get blindsided and the exam looks nowhere near what it looked like in previous years. It totally depends on who is in the committee and what they wish to ask. This is where having an eccentric faculty member in the exam committee is not to your advantage.

Fifth, how do they determine who passes and who doesn't? From what I've seen, schools have done both curving the results, or have a fixed exam score as the passing mark. However, this is only a guess on my part, because most schools do not tell you before hand (or even after) how this is done. Sometime this even change from year to year. I have only heard unofficial remarks on how the cut-off was set. So I have no inside information on this one.... yet!

Finally, the worse thing you can do to yourself is worry yourself to death! Granted, this is probably the biggest obstacle you will ever face in your graduate studies. However, people DO pass the exam, ordinary people like you and me, and not superhuman geniuses. What you need to do is focus your life on the exam, devise a systematic study approach, and cover the things that you know that you must know cold. Again, get a study partner who is in the same boat as you are. Split the exam questions so that you two can cover a larger scope, and discuss the solution. I think most students who passed the qualifying exam did this (I certainly did). And try not to lose your sanity. Get enough sleep, eat properly, and take care of your health. You (both your mind and your body) will need to be at your best when you enter the examination hall.

Part X: Choosing a Research area and an advisor

In the previous part, I described the trials and tribulations of going through the qualifying exam that almost all graduate physics students have to go through. In this part, we will assume that you got through that very difficult part of your graduate program and now ready to do some serious, real physics work - choosing a research area and an advisor.

I neglected to mention last time that when you first enter the graduate program, very often, you are assigned a faculty member at random to advice you on what you need to do the first year or two before you actually choose an area of specialization. This is because most physics students will be taking roughly similar classes that are part of the required set. Your initial advisor can be helpful in determining if you need to do a refresher course in advanced undergraduate classes to prepare you for the qualifier. In any case, there's a good chance that you will not maintain the same advisor once you decided to specialize in a particular field of physics.

So now what happens after you pass through your qualifier? If you're lucky (or stubborn), you would have an idea of an area of physics to go into. In many large schools, there usually is more than one faculty member working in that area. If not, then do what I did - shop around. Start with the department's graduate program description. Figure out who is doing what. Then ask other graduate students, especially the senior ones, what so-and-so is doing, if he/she has research grant money, etc. I will give you my criteria on choosing an advisor:

1. And obvious one, is he/she knowledgable or a well-known expert in that field. This is a given, but you'd be surprise how there are faculty members who are clueless in the latest development in a field of study. This is especially true of he/she doesn't have research fundings and thus, do not often travel to attend conferences, etc.

2. Is that person available for easy contact? This may be surprising but consider the fact that many research projects requires one's presence elsewhere, even out of the country. There is no point in choosing someone well-known, and have that person not available often

for you to talk to. Worse still, some time you are assigned to a post- doc to supervise your work. This may or may not be a bad thing, but you should at least be aware that this is what is going to happen before you go into it.

3. But most importantly (at least in my book), can you get along with this person. I have seen way too many sad situations where the mentor and the student are simply either miscommunicating with each other, do not understand each other, or simply cannot get along. This will make for a hellish experience and I have never seen anything good coming out of such a thing.

Choosing an advisor is the next most important task you have to do after your qualifier. This is the person who might determine your future, and certainly your professional future. An excellent advisor will not only advise you on the official requirements that you must complete for graduation, but also train you to become a good physicist. Such training are not covered in the school's bulletin or official requirements. Yet, these are the stuff that could be more important for your future as a physicist. Your advisor needs to tell you the state of the knowledge in that field of study so that the two of you can decide on a particular work that you can do that will become your research dissertation. He/she needs to make sure you start to establish your reputation by making sure you get to publish a few papers in respected physics journals. And as important, he/she will make you attend and present your work at various physics conferences so that you acquire the ability to speak in front your peers and experts in the field. This will also serve to give you visibility to others in the same field, gives you the opportunity to know who's who in your field, and make contacts. Never, ever underestimate the benefits professional contacts - you will come to value those if you continue in physics.

So if your advisor cares for your development as a physicist, he/she will take steps to ensure that you will have such an experience.

There is one thing that I should also mention : pedigree. Having a very well-known physicist as an advisor often can play a big role in one's future. For example, as far as I can remember, practically all of Phil Anderson's graduate students at Princeton went on to hold prestigious faculty positions at prominent schools. The same can be said with a number of other famous physicists. Of course, these people get to choose the cream-of-the-crop candidates in the first place, so that already ensure that these students are some of the best minds there are. It is why many students clamor for well-known physicist, because in the ensuing competition for post-doc and employment, who your advisor was can be the tie-breaker. My personal observation on this is that this is more prevalent in theoretical physics than in experimental physics. This is because even someone from a small, less well-known school can make a big impact in experimental work, especially if there's access to either a large facility, or a Nat'l Lab. This occurs less often in theoretical physics, and usually well-funded theoretical programs are often found centered around well-known theorists.

In the next installment, we'll go over the daily grind of doing graduate research work.

Part XI: Initiating Research Work

It has been a while since the last installment of this series, so let's recap on where you are right now. You should already made a choice on the physics subject area that you want to work in, and you have picked an advisor who will be (i) supervising your Ph.D research work (ii) the chairperson of your thesis committee.

We will now be in the ”meat” of the whole thing. This is where most physics students entering college have wanted to be - doing research-front work in an area that one has picked, and hopefully, has an acute interest in. Since this is such an important and major part of your Ph.D program, I will devote several chapters to this. I will also describe this from the point of view of someone who worked as an experimentalist, so some of the advice being given tend to be more applicable to experimentalists than to theorists. But in general, most of the generic events and steps tend to be quite similar.

The first thing you have to get rid of is the notion that doing research work is ”glamorous”, exciting, 30-thrills-a-minute type of work. Nothing could be further than that. A lot of time, you will be sitting on your rear end, waiting for something to either occur, or finished. Sometime it requires taking a graveyard shift, late at night. Often, you have to do physical labor work, crawling under things, doing repairs, etc. Or, you are sitting in front of a computer monitor at 3 AM trying to find the bug in your codes. I’m telling you all this now to make sure you do not go into this with the wrong set of misconceptions. While doing research work CAN be exciting and fascinating, most of the time, it can be downright boring. So be prepared for such things and adjust.

One of the things that one MUST do as soon as one selects an area of study is to figure out the STATE OF KNOWLEDGE of that field. You need to be aware of what is currently known, what is being actively studied, what are the ”hot news”, who are the BIG names, and who’s doing what to whom. What this means is that you may end up spending a considerable portion of your time doing nothing but reading tons and tons of papers and journals. Often, you start reading a paper, and then discover that you need to look at the reference being cited in that paper. So you get that reference and it turns out you need another paper or two being cited there! It’s a chain of events that can sometime be quite frustrating, but it is a necessary part of trying to be up to date on the state of knowledge in that field. I certainly know that when I started my Ph.D research work, I spent on average 30% of my time during the first 3 months or so reading everything I could get my hands on about the field that I’ve chosen.

You need to know the state of knowledge of the field for a number of reasons:

(i) you do not want to replicate what has already been done (unless you think there’s something more to be done and that somebody missed something)

(ii) you need to know not only what’s interesting, but what is important.

(iii) you need to be aware of what area is the ”hot” topic, and who is working in this topic. Something that is hot tends to get funding.

Your advisor may have a specific project in mind for you to work on, or you and him/her have already agreed on what you will do, but you still need a broader perspective on what is going on in the field that you have selected. So even though you have decided that you want to study tunnelling spectroscopy of superconductors for example, it doesn’t mean that you shouldn’t be paying attention to the progress in the field of superconductivity in general. You must start to be aware of the whole area of study that, more often than not, have a direct impact on your work.

So be prepared to do a lot of reading and catching up. Don’t be surprised if you end up spending up to half of your time doing nothing but reading journal papers. This is effort you have to put in to prepare you for the next step in your research work.

Part XII: Research work and The Lab Book

Now where were we? Oh yes! You have now started with your actual research work. You and your adviser have agreed on at least the general type of area you will be working in and you have started to do a lot of literature search of what is going on in that field, what is known, what is unknown, what are the hot areas of study, etc. One important note here is that to NOT be rigid in one particular area especially during the early years of your project. In many cases, you and your adviser are still exploring an area of study before both of you narrow down into the exact, specific area that will eventually end up as your thesis research work. The best thing you can do right now is to gain as wide of a knowledge base as possible. If you are working in tunnelling spectroscopy, don't try to limit yourself with just one family of material. If a wide range of material is available and open for study, go for it. You'd be surprise how something that may appear at first to not be important, might turn out otherwise later on. Trust me on this.

What I would like to stress in this installment of this series in the "ethics" of doing research work. I will illustrate this from the point of view of an experimentalist, but there are elements here that are also relevant to theorists. In general, the ethical practice of doing research applies to every field of science, so use what I will be describing as a "case study" and apply it appropriately to you line of work/study.

When I used to conduct physics laboratory session for undergraduates, one of the practice I tried to instill onto my students was the writing of everything they did and observed during the experiment into a laboratory book. I want them to acquire the skill of writing these observations clearly, to write down what they are doing, why they are doing it, and their observations, even to the extend of writing down what they are thinking regarding the data they collected. Was there something peculiar? Are there something not working correctly? Are the data consistent with something else? Are things just making no sense? Are the equipments malfunctioning or not giving the expected results?

Not only that, I wanted them to write all of these in INK, and I prohibited any "erasing" of anything they wrote in their lab book. If they think they made a mistake, just cancel it out, but leave it legible. Now was I being psychotic for insisting things like this? I hope not, and I will explain why. In doing research work, it is imperative that you record almost everything clearly. In most cases, it is for your own good, so that if and when you need to figure out what you did later on, you just don't have to rely on your memory, especially if you want to know what you did then, what parameters were used to make such a measurement, etc. However, there is also another important reason for such a record. While this doesn't occur very often, when it does, you'll be glad you have such a record. In certain cases where it is necessary to establish who did what, and when, your lab book is often used as official evidence, especially in the court of law. If you work for an institution, be it governmental, academic, or commercial, the lab book is the property of that institution (i.e. you can't take it with you when you no longer work for that institution). If there are disputes, questions, issues, etc. arising out of your work, your lab or record book is the definitive evidence in such matter.

This is why you should always write your entries with a date and in ink. You want as permanent of a record as possible. In addition, if someone else comes in and want to reproduce your work, this is the ultimate source to see what was done exactly.

We have seen cases where improper or lack of record-keeping created serious consequences. The infamous Schon debacle at Bell Labs is the most recent example. The fact that he could not show any written record of his experiments (he could not produce any lab books of his experiments) created a serious doubt on the validity of his work. This resulted in his fall into disgrace - he was fired from Bell labs, a large portion of his published work were retracted, and his alma mater withdrew the granting of his Ph.D degree.

Now granted that things like this do not occur very often (luckily), but many smaller forms of double-checking do. It is never too early to make sure you keep a careful record of what you are doing. Even if you are a theorist, it is always a good idea to make sure your work and ideas are kept in a record book. Not only will this allow you to go back and remember what you did (or why you were doing it), but it allows others to understand what you did and when you did it. Besides, if you win the Nobel Prize and become a world-famous physicist, they'll want your doodling to be put in a museum or some place! :)

Moral of the story: keep as complete of a record of your research work as possible.

ADDENDUM: I know I sometime have an uncanny timing, but this is ridiculous!

In the just released online edition of Nature (22 September 2005), a news report about the embattled japanese researcher has indicated that his lack of record-keeping is casting doubt on his work. The report says that

"*A respected Japanese scientist who failed to produce laboratory notebooks confirming his published results now faces a furore over the credibility of his findings. On 13 September, the University of Tokyo's School of Engineering held a press conference to say that Kazunari Taira, a professor at the school who specializes in RNA research, had not provided raw data to verify his team's results. The RNA Society of Japan has also questioned some of Taira's methods.*"

So kids, I'm NOT making this up when I say that you'd better start learning to write everything down on paper when you are doing something related to your studies/work. It may be a boring and tedious task, but when stuff happens, you'll be sorry that you didn't.

Part XIII: Publishing in a Physics Journal

At this stage, you are well into your Ph.D research work, and depending on what area of physics you are in, you may already start producing new results. This next part of the series will cover an extremely important aspect of your graduate work that is typically not covered (some time not even required) in your graduate school requirement. It is the aspect of publicizing your work. Your graduate school curriculum will not have much, if any, on this. Yet, as a physicist, this is one of the most important aspect of your profession.

There are two major means by which physicists publicize and report their work - via physics journals, and via presentation at physics conferences. In this chapter, I will first cover journal publications and will reserve conference presentation to the next chapter.

If you have ventured into your library, you will notice that there are hundreds of physics-related journals, or journals that accept physics papers. While a lot of these journals tend to specialize in a particular area of physics, there are three journals that are considered to be very prestigious for physics publications: Nature, Science, and the Physical Review Letters.

Nature and Science publishes science papers in general, not just physics. They also tend to be extremely selective on what appears on their pages. One criteria is that the work being reported must have widespread appeal or importance, not just within the confines of that particular area of study. So things that claim a discovery of never- observed phenomenon, such as fermionic condensates, or apparent superluminal group velocity propagation, are the types that the editors of these journals look for. This criteria adds to the difficulty in getting published in these journals. In many cases, manuscripts submitted to these journals do not even get passed the editors. They are often rejected before the manuscripts reach the referees. Phys. Rev. Lett. publish exclusively physics and physics-related papers. Because of this, they tend to publish more physics papers per week than Science and Nature combine. But they are no less difficult to get through. The editors, while still more forgiving than the editors of Science and Nature, will ramp up their review of the submitted manuscripts and will be more discriminating of what they sent to their reviewers. Now unlike Science and Nature, Phys. Rev. Lett. has a page limit to 4 typeset pages. So articles submitted to be published in this journal will have to be able to convey their messages within that limit.

I will now describe the typical process that one goes through in trying to get one’s work published in a physics journal. Since the largest ”family” of physics journals is the Physical Review series, I will use the process of getting published in one of these journals as a concrete example. However, the method is quite generic and can be adapted to any reputable physics journal.

To publish a work, you need to be very clear what is the single, most important message you are trying to get across. Once you, your adviser, and your collaborators agree on that message, it is time to figure out how to convey that in the most effective and CONVINCING manner. Figure out what results must be included, what data must be presented, what figures are needed, and how to show all of these in the clearest possible manner. There is no point in having an important thing to say, but saying it in a confusing, obtuse manner that makes it difficult to understand. Your message will tend to be lost, not only to the reader, but more importantly, to the people who will review your work. This is a formula for a rejection.

Once you have decided what to present, you will have to decide where you might submit such a work. Note that in many instances, this is often decided later, after the manuscript is written. However, more often than not, your adviser and collaborators will know how significant the work is, and will already have some idea in mind on which journal to aim for. If this is the case, go to the journal website, and look for instructions to the authors. The journal will have a clear set of guidelines on the format that it will accept for submission. Often, they also will have a template that one can use as a guide. This is especially helpful because it can allow you to typeset your manuscript to look like what it would appear in the final print. It allows you to judge the length of your paper, which is important for journals like Phys. Rev. Lett. that has a page limit.

It goes without saying that you should already be familiar with the journal you want to submit to. All that literature search that you did while trying to familiarize yourself with the field of study that you went into (see an earlier So You Want To Be A Physicist chapter) should make you comfortable with many physics journals. So look at a paper from that journal and pay attention to how the authors present their work. This will be a very good illustration of what works.

Now that you know what to write, where to send it to, and how to present it, it is time to write. This is where you will regret all those complaints you had in your writing classes. It is most likely that if you were the one who did the significant portion of the work that you will be the one to write it. All journals require that the manuscript requires an abstract, an introduction, the body of the work, and possibly a conclusion or summary at the end. This is true even if there are no structured sections that is part of the style given by the journal. Such things are helpful for people who want to do a quick browse of a paper. When you have understood this, then write! Keep in mind one unavoidable fact: your manuscript WILL go through several iterations before everyone involves will agree to it. This happens to everyone, no matter how many times we write and publish our papers. You will learn that different people prefer certain phrases, emphasis, style, etc. Do not be discouraged by this. Discuss why you think certain things should be said in certain ways (example: Why should you not say ”this results proves that...” rather than ”.. this result is consistent with...”). You will learn how certain words and phrases can cause problems during the review process that you may not anticipate. These are all things that you will pick up along the way as you write your first, and subsequent papers. There’s no way to learn other than by doing it yourself.

Note that it is not unusual for a number of people to share writing the manuscript. Maybe someone will write one part of it, and you write another part, while your adviser writes the rest. However, what is more common is to have just one person starting out by writing the first version, and then it gets passed around to a number of people for corrections, additions, modifications, etc. I find this to be more efficient than the first, and the paper tends to at least be more coherent as a whole rather than a mishmash of different styles.

Physics papers tend to have figures, especially graphs. You need to have a good graphing software. This goes without saying. You will also need to be aware that the figures tend to be rather small when it appears in print. So make sure your letters and numbers will be legible when they are compressed to the typical size of that journal. This is where having a template from the journal and inserting the figures yourself can be useful. You can see how it may appear in the end and see for yourself if you need to make certain things bigger/clearer. See if your figures have too much clutter that someone who is not familiar with your work will find it difficult to decipher what you are trying to convey. Always keep in mind that you are trying to convey some information to someone who is not familiar with what you are doing. Being brief and right to the point are always important.

Unless you are Albert Einstein, your paper will have references. Again, look at a paper from that journal to see the format on how references are cited. However, more importantly, you need to make sure you did not miss an important work that needs to be cited. This is where your adviser will be useful. He/she will probably know what you should include in your citations. If you don’t, don’t be surprised if the referee will come back and ask you why you missed so- and-so. This is where, if you have followed the earlier advice on doing an extensive literature search, you would have known who did what when and why such a thing needs to be included. Be aware that you can ruffle a few feathers if you left out something you should have cited. The people who are also in your field will tend to remember that you neglected to cite their work when it was appropriate to do so. They might just do the same when it is their turn. You do not want to put the wrong foot out especially when you’re just starting out. So do your homework.

Who to list as the authors on your manuscript is initially the decision of your supervisor/adviser. If you did the work, and are the primary writer, you should be listed as the first author. However, this rule is not followed all the time. Sometime, unfortunately, it is a matter of politics on who gets listed, and where. Typically, those who did the most work gets listed first, and the list follows on the degree of contribution to that work.

[*Addendum to the original article - In experimental high energy physics papers, the number of people participating in the work can be HUGE, often more than a hundred. It is usually difficult to pick a single person who did more work than others in such a collaboration. So for such papers, the authors are listed alphabatically using their last names*.]

I suppose this is also the place to tell you that if you do not know how to write LaTex codes, this is the time to learn. The Physical Review journals, especially, prefer LaTex format as the submission document, while the figures have to be in postscript (PS) or encapsulated postscript (EPS) files. There are several graphical Tex editors that allows you to type your document and mathematical equations very easily (the FULL version of MathType Equation Editor that comes with Word can convert equations into LaTex codes). So you don't really have to learn that much. Note that if you submit your documents in the format that they prefer, you get a discounted publication fees for Physical Review journals (more on this later).

When you are ready with a final manuscript, it's time to submit. All of the major journals now prefer electronic submission. Go to the journal's website for explicit instructions. Once you have submitted your manuscript, you will be given a manuscript or submission code. This is the reference number you and the editors refer to whenever there's communications between the two parties. It is also the code that the referees are given if and when your manuscript is evaluated. The editors will determine if your manuscript satisfies the standard requirement for the journal. If it does, it will be submitted to either one, or more than one referees. For journals such as Science, Nature, and Phys. Rev. Lett., 2 referees are normal, 3 is not unusual, and 4 or 5 is not unheard of. These referees are anonymous to you, the author. On the Physical Review author's webpage, you can actually track the progress of your manuscript and at what stage it is in. So you can tell if it has been sent to the referees, and when the referees have responded back to the editors.

The responses from the referees determine the next step that you have to make. There are several possible outcomes:

(i) ALL the referees gives a positive review and agree that your manuscript deserves to be published. You may need to make minor changes, but overall, it is accepted. Then congratulations! The editors will give you instructions on what you need to do if you have to make minor modifications, etc. But don't get used to this. This doesn't occur often. More likely on what would happen is option (ii)

(ii) which is one referee has a set of comments/questions, but gives a positive review, while the other referee doesn't give a positive review and also have comments/questions. When this occur, you will have a chance to submit a rebuttal, and make changes to your manuscript to take into account the referees' comments, suggestions, etc. I strongly suggest you make a much of an attempt to accommodate the referees' suggestions. It will shows that you respect their opinions and may make the 2nd round of review smoother. You then resubmit your manuscript and usually the same referees will get to review it again, unless one or more of the referees refuse to review it again for some reason (this has happened before to yours truly). If all goes well, you'll get all positive review and your paper is accepted. But it can happen that even after the 2nd round, you still do not get a unanimous approval. When this occurs, you need to pay close attention to the journal's policy. Most journals would view this as an automatic rejection. You might as well try to submit your manuscript to another journal. Some journals, such as the Physical Review journals, will give you the final option of appealing to the associate editor. You'd better have an extremely good reason to do this because it will again take some time for the process to occur and you really, really want to get your work published in that particular journal.

(iii) you get all negative reviews on the first round. This again will usually result in an automatic rejection. You can appeal or send in a rebuttal, but there's a good chance you won't get through if the editors see that all the referees agree that it shouldn't be published. If this occurs, my advice is to go to a different journal.

Writing papers is a necessary part of your career as a physicist. Many started out with a series of publications by the time they completed their Ph.D work. You need to established your reputation by the time you graduate, to make your credentials stronger in your search for post-doctoral position or employment. Your adviser should help you in making sure you have a few publications under your belt by the time you are done. So such an exercise is a necessary practice in becoming a physicist. You should not be satisfied with your graduate work until you have at least a publication to your name.

Part XIV: Oral Presentations

I mentioned earlier that there are two ways for physicists to communicate their work. The first is via publications in peer-reviewed journals. I have covered this in the last chapter of this series. The second, which we will cover here, is through oral presentations at various scientific conferences.

Each year, there are scientfic conferences, workshops, etc. in various parts of the world, and for various scientific disciplines. In physics, there are many such conferences, often specific to a particular area of physics. However, there are two major physics conferences that are held yearly and typically receive the largest yearly attendence by physicsts from all over the world - The American Physical Society (APS) March Meeting, and the APS April Meeting. The March Meeting is typically the largest yearly physics conference, with attendence in excess of 5000. In fact, the APS Centenial meeting in 1999 in Atlanta brought more than 11,000 attendees, including all the living Nobel Laureates in Physics and Chemistry. The subject matter covered in these two conferences differ, and you are recommended to go to the APS website for a listing of all the various divisions and when they meet (www.aps.org).

There are two major reasons why a physicist would attend a physics conference. The first is of course the need to present one's work. While printed publications can also accomplish that, there is nothing that beats a human interaction in conveying an idea. It works both way - the presenter can present his/her idea in a clearer fashion, and the listener gets a more detailed or dynamic presentation, allowing for possible questions of things that aren't that clear. And let's face it, there is a huge amount of papers being published. Your work can often be overlooked. This is one way to make sure people pay attention, and allows you to argue on its importance to the field of study. Sometime, you do have to trumpet your own horn.

The second major reason is the interaction with others who are your peers, or will be your peers. Presenting a talk at a physics conferences is one way for you to get people in your field to recognize you. Chances are, when you are done with your studies, these might be the very same people who might be the ones you seek employment from. It is never too early to make a name for yourself, and for people to start recognizing your name and your face (not to mention, your ability). Do not underestimate the importance of making contacts.

Furthermore, in terms of the workings of physics, you will be very surprised to learn that a lot of important insight and progress are often made at these conferences, especially when you're sitting down with someone discussing something during a coffee break, or simply standing outside the conference hall. I've lost count how many important ideas that I've gathered simply by discussing things with others. The majority of us do not, and cannot, work in isolation. These conferences offers us the latest news on who is doing what, the latest results that may have not yet even been published, and simply the ability to judge the "winds of change" on what might be the next important direction where the field is heading. In fast moving fields such as superconductivity, by the time one reads a published paper in a journal, that particular issue may no longer be the "hot" topic. These conferences can truly give you a gauge on what the community is heading to, and what is considered to be the important topics. You may not want to go along with the trend, but at least you know what it is. The point here is that there's a lot of physics that is done at one of these conferences, and often there are many new stuff that you haven't heard about.

OK, now that I've hopefully convinced you on the importance of attending such a conference, how does one prepare for it? Often, your adviser will be the one suggesting that you attend one of these, at least a couple before you graduate, to present your work. So hopefully he or she will also have a plan to get you ready for it. This could be done by first discussing in exact detail what you should be presenting, what should be on your transparencies or viewgraphs, etc. A lot of advisers would ask that you do a practice run. He or she will either have you present it in front of him/her, or call on other graduate students to attend your practice and try to ask you all kinds of questions. This will allow you to see if there's any part of your presentation that is weak or unclear, and also give you an idea on how long your presentation is. These conferences some time can have tight time limit, and you need to make sure you are not running long and have to omit important part of your work.

There are many resources you can read on making a good presentation. A polished, well-done presentation is a joy to sit through. A poorly thought of presentation is a bedtime story waiting to happen, and a torture to sit through. While you may not care if people are bored or not, my philosophy has always been that if I have to do something, I might as well do it as best as I can. So the following is my suggestion on how you should organize your talk, based on my experience at giving and sitting through many of these throughout my career.

1. Organize your thought. Sit down, and figure out the sequence of items that you will be presenting. Make sure that it is clear enough that someone who doesn't quite know your field might have a chance to understand. But here, you have to know the kind of audience you might be facing. If you are presenting this at a conference specific to your area of study, then you can skip a lot of background information that the audience already know. On the other hand, if you are presenting this to a mix audience, then expect to put a little more background info on the physics and maybe even the technique involved. From that point, look at the logical and sequential flow of the info that you will be presenting. Is there too abrupt of a jump from one viewgraphs to the next? Can one see a connection from one to the other?

2. Keep in mind that out of sight is out of mind. You shouldn't expect too much that the audience will remember previous viewgraphs that have gone passed them. So your viewgraphs should try to contain as much relevant information as possible. However, the trap here is that you may make it too full and too convoluted that it is difficult to read. What you need to keep in mind that (i) lots of equations don't help, unless you are a theorist and presenting a talk to only theorists (ii) pictures and graphs are good, IF they are properly annotated. Never, ever, present a graph or data without clearly indicating on the viewgraph itself what it is, what the quantity represents, and all the pertinent information. (iii) A very concise but brief description in words of important points you want to make on that viewgraphs. Do NOT, I repeat, do not write lines and lines, or paragraphs of descriptions. If the audience is reading this, chances are, they are not listening to you. So why are you even there? Besides, it is annoying having to read a lot of things on a screen - one can get that by reading a paper. So limit only to the important points that you want to get across. This includes the description of the pictures or graphs that are shown, and any relevant parameters. For example, if there are two different graphs and you are trying to compare the two, write in point form their similarities and differences. This accomplishes two things: you can look at the screen itself and be reminded of the things you are trying to convey and can emphasize them verbally, and the audience can read them and along with your oral

presentation, be reinforced on the important point that you are trying to get across. This is also helpful if you are not a native English speaker and your English pronunciation is weak. Having the points written on the screen can still allow the audience to have an idea what you are trying to say. But again, do not write lengthy prose and expect the audience to have the patience to read it.

3. Here's a mistake that I see many presenters make - they are OBLIVIOUS to the audience. What this mean is that either the presenter spent most of his/her presentation talking to the screen and not even looking at the audience, or the presenter did not pay attention to the audience reaction. While an oral presentation is you standing in front of people and giving a talk, it really is a two-way street. You have to judge if what you are saying is getting though (after all, that's the reason you are there). Look at the facial expression of some of the audience members. Do you see a puzzled look? Do you see a bored look? Is the senior physicist nodding his head off to sleep and about to fall off his chair at any moment? It allows you to judge if you have time to go back and re-emphasize certain points that may be unclear. Of course, you do this after you are quite skillful at doing one of these presentations AND you have the luxury of time management. But it is still important to judge how your audience is reacting. A good presenter can tell if he or she needs to make the presentation clearer and not just stick to the "script".

4. Learn from other presenters. By now you should have already attended several talks, department colloquium, seminars, etc. Learn from them what to do and what NOT to do. Start paying attention to the slides and viewgraphs that you are seeing. Is that clear, or not very clear? Is it too packed with info that the message is lost? Is the person going way too fast that you don't have time to properly absorbed what is being said?

5. Timing and pace are very crucial. Figure out how much time you have. This will limit on the number of viewgraphs you can have. Most people will tell you that you estimate that you will spend 1 minute per viewgraphs. So this means that if you are given 20 minutes to talk, you should have 20 viewgraphs. I personally find that very unrealistic. I would do LESS number of viewgraphs. Chances are, you will have to do quite a bit of explaining, and you need to allow yourself some margin for error in case someone interrupts you during your talk to ask a question. It also can allow you to go back to an earlier viewgraphs if you need to and explain some things. In my book, it is better to end early than to end too long. It allows for more time for question and answer. Also, what many people do (and I do this often), is that you have extra viewgraphs in case you do have time left. These viewgraphs should be considered as "bonus", in that you don't really have to include them if you run long or on time, but in case you do have time, you can include them.

6. Don't expect the audience to remember what you said, at least not everything. This is where trying to emphasize one, or two points, is important. Try to sum up the "moral of the story" at the very end, to make sure they are aware that this is what you are trying to convey, and why it is important. You should try to make sure that you leave them with at least one thing that they remember. That's all you should expect.

7. Practice, practice, practice. Your first few times at doing this may be nerve-wrecking, and may not even go well. Unfortunately, the only way to do this well is to do this many times. It is a skill that can only be acquired through practice. You will learn what works and what doesn't.

By the time you are done with your graduate work, you should have presented at least once to an audience of professional physicists in your field of study. You should not be happy with your graduate training if you haven't done so. If you intend to pursue a career in physics, chances are, your employer would want you to prove that you have the ability to talk in front of an audence as one of your communication skills (read the physics job advertisements if you need any more convincing). Conveying the importance of your work in front of an audience, be it people from a funding agency, other physicists, or just the general public, is a necessary skill as a physicist. You should have such skill by the time you are done with your Ph.D training.

Part XIII: Publishing in a Physics Journal (Addendum)

When I first wrote this part of the series, I wasn't quite sure if I should include this. for most people submitting to most of the physics journals, this isn't an issue. But considering the number of very bright students we have on here, inevitably some of you might consider submitting a manuscript to Nature or Science. When you do that, then you will start learning of the meaning of the word "embargo".

First, a bit of background. Many people are familiar with the electronic e-print ArXiv repository. Many scientists upload their preprints there almost at the same time they submitted their manuscript to a journal. It is also a common practice that scientists discuss their work either via presenting it in a talk at a seminar or conference, or by putting it up somewhere on a webpage.

Most journals have a "first right of publication" policy. This means that the work being publish must not have appeared anywhere else. Additionally, Nature and Science have an embargo policy. To many people, this policy means that a submitted work to Science or Nature cannot be distributed or discussed in any form or means, including uploading it onto an e-print server. Such distribution will cause an automatic disqualification from being considered for publication.

Having gone through the process of submitting to Science and Nature, I have a bit of first-hand experience in dealing with this. I have also talked to one of Nature's editors regarding such a policy and obtained a more definite clarification on this.

First of all, this is what you can find on Nature's webpage regarding their embargo policy (this is only a part of what you can find there):

"Nature does not wish to hinder communication between scientists. For that reason, different embargo guidelines apply to work that has been discussed at a conference or displayed on a preprint server and picked up by the media as a result. (Neither conference presentations nor posting on recognized preprint servers constitute prior publication.)

Our guidelines for authors and potential authors in such circumstances are clear-cut in principle: communicate with other researchers as much as you wish, but do not encourage premature publication by discussion with the press (beyond a formal presentation, if at a conference)."

http://www.nature.com/nature/authors...y/embargo.html

What this means is that there is no restrictions in scientific discussions of a submitted manuscript. This includes scientific presentation at conferences, uploading the manuscript on ArXiv, etc. What is not allowed is a discussion with the media or journalists until 1-week before the publication of the work. However, and this is something that the Nature editor told me, if during your scientific discussion or presentation, another media decided to use it and report it, then you have inadvertently violated the embargo policy, and Nature has the right to refuse publication. This has happened before, and I have seen other media reporting on an ArXiv paper that hasn't been published yet. If that paper was meant for Nature or Science, such reporting would have disqualified that paper.

So for many people, if they have submitted to Nature or Science, they tend to wait before uploading the manuscript on ArXiv, or even presenting a partial result at a scientific conference. While violation of the embargo policy resulting in disqualification is rather rare, many people tend to take the more cautious route and wait a month or two before reporting the complete work.

Part XIV: Oral Presentations - Addendum

I'll try not to make a habit out of this, but I believe there's something to add to this chapter of the series.

In Part XIV, I mentioned the APS Meetings - March and April - which typically tend to be the largest yearly gathering of physicists. They both covered different areas of physics, i.e. different divisions under the APS wing would meet in March and in April. The March Meeting tends to be the condensed matter, material science, atomic/molecular physics, etc.. whereas the April Meeting covers particle, nuclear, astrophysics, etc. I have not attended the April Meeting, but I have attended the March Meeting numerous times and have given a talk at all but one of the meetings that I attended. Based on what I have been told, the April meeting, while smaller than the March Meeting, follows roughly the same format as the March meeting. So this description covers both.

The reason why I am going to spend time describing these conferences is because for most physics graduate students, one of these meetings will probably be the conference where they cut their teeth at presenting to people in their profession. Chances are, you will present your first ever professional talk at one of these conferences. This is where you will meet your peers, the people you have cited in your work, the people you read about when you decided to go into your particular field, etc. And chances are, this will be the time you will start to be known not just from your name, but what you look like and how you interact. So rather than going into this blindly, it might be useful to know a bit more of what goes on at one of these meetings. Also, the March and April meetings are unlike other physics conferences due to its size. So if you have attended other conferences, don't be surprised if the March/April meetings appear a lot different.

The March Meeting is HUGE. With an attendance upwards of more than 5000, and with almost every attendees presenting, the scientific program itself used to be the size of 2 phonebooks! At any given time, there are at least 50 simultaneous sessions going. So out in the lobby and in the hallway, it can be quite a zoo, but it is nevertheless a well-controlled chaos, with people jumping in and out of one session into another.

If we neglect the special symposiums, there are 3 different categories of presentations at the March Meeting: (i) invited talk (ii) contributed talk (iii) poster session.

The invited talk is when you are invited by the organizing committee to present your work. This can occur either by someone nominating you to present your work, or someone in the committee notices an important work, usually in scientific journals, and would like you or someone on the authors list, to present the work. This is a very prestigious honor (I strongly suggest you note this in your resume and if possible, save the invitation - trust me on this, you'll thank me later). It means that your work was deemed important enough and deserves to be invited to give a presentation on it at such a major conference.

Now the invited talks can be presented in two types of session. Typically, you may lead off a smaller session of the same subject group and given maybe 20 minutes. Other people that follow you are those giving contributed talks and have shorter time (more on this later). However, sometime the conference committee may deem that a particular area or topic either deserves its own plenary session, or that they have sent out invitations to a number of people in the same subject area. In that case, a special plenary session in a large conference hall is held and each speakers is given a longer time to present their talk (typically 40 mins).

The contributed talk, on the other hand, can feel more like a automated, production-line presentation. The majority of the talks at this meeting is of this category. This is where you submit an abstract to the conference for an oral presentation, and then you are assigned to a particular session (usually with like-minded people in the same subject area). Everyone who registers for the conference CAN present a contributed talk. You have 10 mins plus 2 minutes for question and answer before the next person comes up. So things move very fast and the time is strictly adhere to. This is because in the scientific program (the one that can be 2-phonebook thick) the time that such-and-such talk will occur in a particular conference room is listed. This allows for people who are jumping from one session to the next to know when such-and-such talk will commence. Running long will mess things up, and the chairperson has been instructed to be very strict with the timing.

[This brings up an unusual occurrence where in the case that there's a missing presenter, the next person after this presenter still cannot just walk up and do his/her presentation because that will throw off the timing. His/her presentation has been scheduled for a particular time, and if he/she goes early, someone who may have planned on being there at the start of his/her talk may miss it. So what ends up happening is that people just sit patiently in the room till it is time for the next presenter to begin. I have never seen this occur in other conferences.]

Note that just because it is a contributed session doesn't mean the talk isn't important. I think there's a rule that if you received an invited talk one year, you cannot receive another one the following year (they want to make sure no single person monopolize these things). There are still important work and results being presented in these talks.

The last type of presentation is the poster session. What you do here is present your work in a well-thought of poster that you put up on boards. Depending on your subject matter, you will be assigned a location and a date for your poster to be put up. People wonder through the poster hall continuously during the session, and it is advisable that you (or one of the people working in your group) be by your poster throughout the session. This will allow people who have questions or comments to be able to talk to the people who are responsible for your work. You'd be surprised how much valuable information can be gathered from such conversations. It is also a good idea to attach to the poster board any publications that the poster is based on. Many people attach a large envelope containing copies of the paper for people to take one if they wish. Again, it is a way to "advertise" your work. For most graduate students going to one of these meetings for the first time, they tend to be presenting posters, since it is less nerve-wrecking than doing an oral presentation. This will give them a flavor of one of these meetings so that next year, they'll know what to expect when they actually present a talk.

It is my personal opinion that if you are a physics graduate student in an institution in the US, you should attend one of these meetings at least once. If your adviser does not bring it up, ask. At some point, you will have to produce an original work for your phd research, and this is what you should present at one of these meetings. It is your best chance to meet other physicists in your field. It is an opportunity not to be missed.

Part XV - Writing Your Doctoral Thesis/Desertation

At this stage, you have performed your doctoral research work, maybe even have published (or about to publish) a paper or two, and may have presented your work at a physics conference. It is time for you to think about finishing this part of your life. However, before you can do that, you have a couple more obstacles to get through - writing your thesis/dessertation and defending it. We will discuss the first one in this chapter.

You and your adviser should have narrowed down the main points that you will need to cover in your thesis. More often than not, you would have done more than you need during your graduate research work. It is not unusual that a graduate student has studied a number of different areas within his/her field of study, especially in the very beginning of his/her research work. However, it doesn't mean that anything and everything need to be included in the doctoral thesis. Your thesis must present a coherent research work that you have accomplished that no one else has done. So you and your adviser do need to be very clear on exactly what area that should be included, and what shouldn't. Chances are, if you have published your work in a peer-reviewed journal, the area being covered by that paper would qualify as something that should be covered in your thesis.

Once you and your adviser have agreed on the general scope that should be in your thesis, it is time for you to organize your thoughts and figure out what to write. You should have plenty of practice already by now if you have published a few papers already. So all the advice on writing a paper applies here. Figure out the central points that you wish to convey and try to make your point as direct and as clear as possible. Note also that depending on your school's requirement, you may have to explore the background of the issues/physics in general terms. This is because in many schools, your thesis committee may comprise of not just individuals who are familiar with your field of study, but also individuals from other fields or even other departments. So pay attention to what needs to be covered based on what kind of thesis committee that you will be facing.

When it comes to the actual writing process, this is where you will need (i) your institution's thesis guidelines and (ii) copies of thesis that have already been written. The first one should be available from the graduate school program at your school. Read it carefully. It will tell you a number of things you must follow, including (i) thesis formatting/typesetting requirement (ii) the format and order of the thesis (iii) thesis committee requirements. Pay attention to how your thesis should be written, especially in terms of figures(*), captions, bibliography format, section titles, etc. In some schools, they might even have a read-made template for you to use with your favorite word processor (or even Tex editor) that can make your life easier. Looking at older thesis from your department will give you specific examples on what can and cannot be done. Chances are, your adviser will give you examples of already-approved thesis, or you may even have been referring to one already. So look at all of those as guides. Do not relegate this as something trivial. Your thesis will be looked at by a thesis examiner, who can and will reject it if it does not conform to the format required, and thereby possibly delaying your graduation. Note also that in many schools, the graduate program often has a short briefing on those who intend to submit their thesis in that particular semester. This can be either a 1 hour class, or an individual meeting with the thesis examiner. Make sure you attend this and be aware of what is required.

How long a thesis should be is highly subjective. I've seen advisers who don't care how long it is, while others who don't want it longer than, say 150 pages. I'd say that it should be as long as it needs to be. Don't ramble on and on and turn it into War and Peace, but you also do not want it to be lacking in details, because these are the details that probably no one else has worked on.

As you are writing it, pay attention to the deadlines that you school has listed if you wish to graduate at the end of a particular year or semester. This is very important, because missing it could mean that your graduation will be delayed. If you wish to graduate at the end of the semester, look at first and foremost, when your thesis is due for submission to the graduate program. Now work backwards. Move that date two weeks earlier. Why? This is because you want to be sure that if there's unanticipated problems with your thesis, that there's plenty of time to correct it. So that two-weeks-early date should be the latest you should hand it in. Note that this is your planned FINAL SUBMISSION. This should NOT be the first time you have shown your thesis to the thesis examiner. So you should plan on a meeting with the thesis examiner even earlier than this two-weeks-early date. For the sake of illustration, let's put this as 4 week's early than the final deadline. So 4 week's before the graduate school's published deadline, you should meet the thesis examiner for the very first examination of your thesis. There's a very good chance that you will need to make modifications, hopefully minor ones if you have paid close attention to the required format. This will give you two weeks left to make the correction and to make your final submission two weeks before the graduate school deadline. Confusing? Hopefully, not.

So it does mean that if you wish to have a completed form 4 weeks before the hard deadline, you need to already have done your thesis defense by then. This means you have incorporated comments you received during your thesis defense into your written thesis, AND have received final approval from all your thesis committee members [thesis defense process will be discussed in the next chapter]. This, again takes time. This means that you should schedule your thesis defense at least 2 months before the graduate school's hard deadline (I would even suggest a little longer). This will give you time to make changes, to send the corrected version to all the committee members, to allow for more changes, and then to get their approval. These things can be time consuming, trust me!

So if you have to schedule your thesis defense 2 months before the hard deadline, then you should need to contact your thesis committee members before then to schedule your defense. Sometime it can be a chore to get a suitable date, so plan ahead. It also means that you now have a good idea on when you should be done with the writing of your thesis! So pay attention to that date! It is the clearest indicator that, if you want to graduate at the end of that semester, you must be done writing by that date! Your thesis committee members will need to have your thesis in their hands at least a week before you can call for your defense. So if you work this backwards again, you should have a good idea of the date where you should be all done. Knowing this, it will guide you on when you should start writing your thesis, and how fast you have to work to be done by that date.

Note that, depending on how involved your adviser wants to be, he or she may want to see the progress of your thesis as you are writing it. You may also want to consult with him/her along the way as you are progressing. This may save major revisions afterwards especially if both you and your adviser don't see eye-to-eye. Fine as this may be, you should always keep in mind that the thesis should be your own work and not expect your adviser or anyone else to write parts of it for you.

Hopefully, this guide will give you an idea on what to expect, especially on time management. The last thing you want to have is sleep deprivation while writing your thesis simply because of things you haven't anticipated, or you didn't give yourself ample time.

(*) The issue on how figures can be displayed in a thesis can be a major headache. Most thesis requirements do not allow for color figures because your thesis will be sent to a service that will archive it as a microfilm. This destroys all color effects. In some schools, they will allow you to make two versions of your thesis - one with a color figure that can be used as the distribution/department/library copies, while another for microfilm archive.

Part XVI - Your Thesis Defense

At this point, you have completed writing your thesis, your adviser has approved of it, and you have distributed it to all the members in your thesis committee. It is now time for you to do your thesis defense. Officially, this is the final obstacle standing in your way between you and your Ph.D degree. Needless to say adequate preparations are necessary.

What exactly is a thesis defense? This is where you demonstrate your mastery of the subject matter that you have been researching during your years as a Ph.D candidate. To put it bluntly, since you are producing an original, new work to be added to the body of knowledge of physics, you have to prove that (i) you understand the physics inside out and (ii) you are the world expert on this particular area. In fact, in certain parts of your thesis, even your adviser may not know as much, or as in detail, as you. This is where you have to establish yourself as someone who knows a lot on this particular topic. You must know every single thing that you wrote in your thesis, and maybe even some beyond that, especially if you make specific reference to other theories or experiments. Your thesis committee will try to judge if you are an expert in such a field.

The most important person that should prepare you for your defense (other than yourself) is your adviser. Your adviser would have guided you in the beginning into a research subject that would satisfy the graduate school/departmental requirement that your work is new, original, and something significant that contributes to the body of knowledge. Publishing in respected peer-reviewed journals would be a major indication that your work is accepted as being new and significant. So in preparation for your defense, he/she should try to impress upon you on making sure that you mention somewhere during your thesis defense that such-and-such work that you did was published in so-and-so journal. More importantly, though, is that your adviser might know certain "quirkyness" of certain members of your committee that might help you to prepare for. If a particular professor always likes to ask about "historical significance" of certain things, or maybe he/she likes to always try to include his/her own research area, then these are the things you should prepare for. It is ALWAYS a good strategy that if you happen to have used or cited the work of one or more of the committee members, then you should make sure you mention this clearly. You'd be surprised how well those kinds of acknowledgments can go down. This should be a common practice throughout your career. In any case, in preparing for your defense, talk to your adviser and ask him/her for his opinion. It may be that your adviser would like you to do a trial run at doing your defense. JUMP at such an opportunity. Such practice is always a good idea. Do this in front of your adviser and other graduate students (who should already be keen on seeing what it should look like since they have to go through the same thing soon enough). Such practice should allow for last-minute kinks to be worked out and to prevent major disasters.

How long your defense should take place depends very much on your adviser and the procedure enacted at your school. Most schools leave it entirely to your adviser. In turn, most advisers would prefer a defense that is between an hour to two hours. However, I have seen a defense that took place over a span of 2 days! It wasn't pretty. So in your practice, make sure you pay attention to how long you are presenting your defense. You do not want your audience, or worse yet, your committee members, to fall asleep.

Most thesis defense are usually announced to the public via the usual seminar/colloquium announcement made by your department. So everyone is usually welcome to attend your defense. Typically, the first part of your defense is similar to you giving a seminar. At the end of your presentation, everyone in attendance is invited to ask questions. The committee members usually would not ask anything during this time, but they will pay attention to how you respond to the questions being asked. So do not trivialize a question, even though it came from one of your buddies in attendance. After this question and answer session, the rest of the audience will be asked to leave, and the closed session will be just between you and the committee members. This is where usually the difficult questions will come up. They will disect your presentation and the content of your written thesis. Pay careful attention to what they ask, answer as thoroughly as you can, and acknowledge any comment or suggestion that they give. Sometime, a question can really come out from left field that you simply did not expect, and you find yourself stumbling along. More often than not, if you have a good adviser, he/she might offer a reply to try to guide you into a right path. So pay attention and try to see if you can get any hints there. Just keep in mind that just because you are unable to answer something which might not be central to your work, this does not mean that they will fail you. So whatever you do, do not panic.

After the committee is done with this session, you will be asked to leave and they will deliberate your fate. My anecdotal account of my defense goes like this: they decided to stay in their deliberation for about 10 minutes longer JUST to make me squirm and sweat. At this stage, there's nothing else you can do. Just exhale, relax, and try not to stress out. Unless something really disasterous happened during your defense, you can almost be assured that you have accomplished your goal. After the committee's deliberation, your adviser will officially informed you if you have passed through your defense. He/she will also inform you of any changes that are necessary to your thesis based on suggestions from the committee members. These are the changes that you need to make before getting the final approval from all of them for you to submit to the thesis examiner/graduate school.

Other than that, it is time to rejoice. You have done a significant accomplishment that was not easy, and took years of hard work and sacrifice. In the eyes of many, you are now a Physicist!

However, is that all there is? You can go out now and work as a Physicist? If only life is that simple and straightforward. In the next chapter, we will go back in time to approximately one year from your joyous occasion at completing your studies. Your journey on becoming a physicist isn't done yet just because they are handing you your Ph.D degree.

Part XVII - Getting a Job!

In the previous chapter, we have reached the point where you have finished with your thesis defense, and also thesis submission to the graduate school. You are all set to go into the nasty physics world and look for a job.

If that is your case, then you are SCREWED! You do NOT start to look for a job only after you are done with your defense. This will be too late and should only be resorted to if you have no other choice. So while you think you are done with your physics curriculum, your job future requires that we go back in time to about one year before you plan on graduating.

By that time, you would have an idea on your career path. You should know if you wish to pursue an academic career, an industrial career (for those of you who have this option), or maybe even get out of physics completely. Still, unless you have a Nobel Laureate as an adviser and have made a name for yourself in such a way that there are institutions rolling out the red carpet for you, you should keep your options open. Remember, you will have to start making a living, and ideals will not feed you much.

I will go into the academic career path first since this is the more tedious side. If you do decide to follow this path, then you will have to start seeking a post-doctoral appointment. Most universities and national laboratories will tend to hire new Ph.Ds at the post-doctoral level (note that US National laboratories will not hire a Ph.D for a post-doc position who obtained a Ph.D beyond 4 years of the date of the appointment).

There are two common places to look for openings for a post-doc position. The first is the classified section of Physics Today. Typically, the largest number of openings for post-doc and faculty positions are advertised during the Fall/early Spring for an appointment in the Fall of the following year. So an opening for Fall 2007 would tend to get advertised more often in Fall 2006/ early Spring 2007. This is why you have to start almost a year in advance in your job hunt.

The other avenue to find post-doc openings is during physics conferences, specially the APS March and April Meetings. The APS provides a job service to both job seekers and employers during the conference. You will have to register with the APS and submit your resume. While you don't have to attend these conferences to submit your resume, I strongly advice you to be present. There are professors and schools that will advertise for an opening right on the spot (these are usually posted on the Job Center bulletin boards). So you can also look for something that you might qualify and immediately make contact. Not only that, but in many cases, if you have submitted a resume, you might be contacted by an employer present at the conference, and an interview can be set up during the conference itself.

This is where I will illustrate with my own personal experience. A few months before I graduated, I attended the APS March Meeting to not only present a talk, but also continue looking for a job. I already had an offer from Applied Materials to go into the industrial route. While I was excited with this and would pursue this line gladly, I knew that my first aim was still in academia/research and so I continued to look. Attending the Job Fair at this March Meeting was almost a last-minute decision. As fate would have it, a faculty member was looking for a post-doc to work at Brookhaven, and happened to be well-acquianted with my adviser at that time. He read my resume and figured that with my background and with the "name recognition" from my adviser, that I would be a strong candidate. I received a message from the Job Center of a request for an interview later in the week of the conference. However, without my knowing it, the faculty member seek out when I will be presenting my talk, and attended the session to see me "in action", so to speak.

I found this out later during our interview, and he was satisfied that I fit the bill to carry out the research work that he had planned. While no job offers were made at the interview, I left feeling that it went tremendously well. It was a week later that the job offer was officially made, which I accepted.

The moral of the story here is that in many cases, you truly have to try all the possible avenues, and the Job Fair at these conferences can be quite effective because in many instances, the employers are also there seeking candidates.

The last possible avenue is the one that is very uncertain and something you should not depend on - word of mouth. Often, various faculty members, usually your adviser, would have heard from his/her various colleagues or contacts, about post-doc openings elsewhere, or even within your department. If a faculty member recommends something to you, consider it seriously. There's a good chance that the person looking to hire knows the faculty member, and name recognition alone will give you a leg up on another candidate. This is what I meant by "pedigree" in an earlier chapter of this series. Unfortunately, this situation doesn't happen often, and that is why I said that you should not rely on such a thing happening.

If instead, you are opting for an industrial or non-academic position, then you need to cast your net a lot wider. Sources such as Physics Today and the APS Meetings are still valid, since those do carry non-academic positions (that was how I managed to snag the Applied Materials offer). However, you also need to look at the "trade journal" of the area you are looking for. Solid state physics specialists should look in IEEE journals, for example.

Do not forget to use your school's job placement services. Many employers will seek out new graduates, and your school can also list your resume with employers they think might be interested with your background. Industrial employers will tend to go through this route, especially if they had success with a particular school before. So don't leave out this option.

Again, all of these should be done approximately a year before you plan on graduating. Make sure you have your resume ready. Have it checked properly, and make sure you include ALL publications.

In the next installment, I will go into your role as a post-doc fellow, and how things will look different from that point onwards.

Part XVIII - Postdoctoral Position

If you intend to pursue an academic/research career, chances are, you will need postdoctoral experience. This is typically a 2 to 3-year appointment either at a university, national laboratories, or industrial laboratories such as Bell Lab. It is not uncommon for someone to do 2 postdoctoral positions before finding a suitable employment. So this part of your career could drag on longer than expected. However, for most candidates, this could easily be the most productive part of your career and when you can effectively make a name for yourself.

A postdoctoral position is usually created out of a research grant. It means that funds have been allocated to hire a person at that position for the duration stated. Once that duration ends, the position will also end. This is why it is a temporary position. In some cases, if the institution has an opening, they might consider you for a permanent position. However, you should not depend on this and should always consider it as temporary.

The reason why a postdoctoral experience is usually deemed necessary to obtain highly sought-after position in leading universities and national laboratories is that these institutions want to employ individuals who (i) have shown the ability to carry on world-class research work on their own (ii) have the creativity to find new and important things to study (iii) can seek funding. These are the skills that one obtains and can demonstrate while a being a postdoctoral appointee (seeking funding may not be relevant for a postdoc in many areas such as theoretical work, or in large projects such as high energy physics).

Unlike your position as a graduate student, a postdoctoral appointee is expected to hit the ground running. Presumably, with your Ph.D, you were hired for your expertise in a particular area. You also have quite a bit more freedom in pursuing the particular area of research. While the broad outline of the area of study is set by your supervisor, you essentially can, in fact, discuss with him/her a line of research that you think should be pursued. You are **expected** to be able to work independently and show your creativity in that field of study. Your supervisor is no longer there to hold your hand the way your Ph.D adviser did.

If your appointment is with an academic institution, part of your responsibility may also involve some form of teaching or academic responsibility. Again, while such responsibility may take you away from doing research work, consider it as added experience that you can add to your resume as you continue to seek a more permanent position. It can only be an advantage to be able to include teaching experience in your job application, especially if you apply to an academic institution. So do not look at such responsibility with disdain.

During your postdoctoral appointment, you are highly expected to publish a few papers, preferably in leading journals. You are expected to know how to go about doing this. You may also be expected to supervise graduate students who will learn from you and your expertise. This is your chance (and even responsibility) to give back what you were given while you were a graduate student.

The issue of funding is a bit difficult to tackle because in many cases, it really depends on the institution. In some institution, the very fact that you can get research funding on your own might be the impetus for them to continue to hire you as a staff member. In national laboratories, you might be expected to be able to seek funding via what is known as the LDRD (laboratory-directed research and development), which are short-term fundings for projects that are potentially capable of receiving larger external funding. Remember that you are there only temporarily. Your ability to attract funding may in fact make you more attractive to be hired, or simply lengthen your postdoctoral appointment. However, you should try to learn as much as possible (probably from your supervisor) on how to seek research funding. Try asking him or her to see an example of a research funding proposal that has gotten through. In physics, the majority of research funding comes from the US Dept. of Energy (DOE) and the National Science Foundation (NSF). Go to their websites and look carefully at the requirement and format to submit a research funding proposal, even if you don't intend to write one. Chances are, you will need to know how to do one of these sooner or later.

Throughout your appointment, you should not stop continuing to look for job opening. It may turn out that as your appointment ends, you may have to seek a second postdoctoral position. Note however that for US National labs, there is usually a 6-year limit from the date that you received your Ph.D to qualify for a postdoctoral position. So if you have received your Ph.D longer than 6 years ago, you no longer qualify for a postdoctoral position.

As temporary and as uncertain as it is, to me, the postdoctoral period is when one truly begins to feel like a physicist. One is now doing directly the type of work one has been dreaming off all those years. There is also little to no other distractions away from one's work, so this is what a physicist truly is, in the purest sense. You will realize later on that as one finally obtain a more permanent position, one is also saddled with other administrative responsibilities that come with the job. So look at the postdoctoral position as the buffer, or transition between your life as a student having a mentor, to being a physicist where you now have to make your own decisions. This transition period may be your most productive and the last time you get to be single-minded on a particular area of physics.

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Part XIX - Your Curriculum Vitae

I am going to backtrack a little bit and talk about writing your Curriculum Vitae (CV) and what you should focus on in search for a job in physics. This includes looking for a Postdoctoral position, a research position, and possibly a faculty position at a university.

I am going to base this on my own personal experience in hunting for jobs, my conversation with others who were in my position, my discussion with other supervisors who were looking for candidates for a position, and my own experience in browsing applicants' CV to fill a couple of positions. I would say that most physics applicants do not pay that keen of an attention to their CV, and one sometime wonders if they are truly interested in a particular position that they are applying for.

Here are the items that MUST appear on your CV:

1. Name, mailing address, e-mail address, phone number;
2. A brief (one short paragraph, or even just a sentence) on your goal;
3. Your educational background. List in reverse chronological order, i.e. the last degree obtained first.
4. Your skills, expertise, and knowledge;
5. Other awards, recognition;
6. List of publications (if there's too many, list the more important ones, or the ones relevant to the job you are applying to).

Try not to exceed more than 2 pages. Keep in mind that people who are reading this have to read a lot of other CVs from other applicants. If it is too long, one loses interest very quickly.

Most of what I've listed above are pretty self-explanatory, and most applicants know what do write, except for #4. This is what I will try to discuss in the rest of this chapter. From what I have read of a number of CVs lately, this is where many applicants drop the ball.

Most CVs that I've received wrote way too much on the "physics" content. Now, such a thing may be appropriate in some circumstances, especially if you're applying in the very exact, same area of knowledge as your research area. The person who is hiring would probably know the subject matter quite well, and would be very interested in it. However, this is also not very common. What occurs most of the time is that you are applying for a position, especially for a postdoc position, in which the subject area is a bit different, some time VERY different, than the subject area that you majored in. What is in common are the skills and expertise that you have that the potential employer is looking for. So HIGHLIGHT THE EXPERTISE AND THE SKILLS in the CV! Don't bury it under lots of physics and don't simply mention it in passing. Not only are you not showing to the potential employer what he/she is looking for, but it also shows that you simply sent out a generic CV without bothering to tailor it to this particular job position. I had that impression many times while reading several CVs.

Let's do an example. Say I'm looking for someone who can make photocathodes for some particular application. Now, I'm not looking for someone with an exact background who majored in photocathode physics, because it isn't a common area of specialization, and there probably isn't that many students who graduated with that knowledge. However, I am looking for someone who has the expertise to make material fabrication. In particular, I'm looking for someone who has the expertise to make thin films of semiconductors, using various deposition technique, especially chemical vapor deposition (CVD).

Unfortunately, it was hard to find that in many of the CVs that I read. Most of the CV talked about the physics (or chemistry) of the material, what was studied, how the physics was important, etc. In cases where the applicants did mention about making thin films, the skimped on the details. I would say something like this: "*Ability to make thin films for XRD and XPS studies to arrive at the strain-stress effects on the band structure*". Yes, what WHAT did you use to make the thin films? That is what I am looking for, and you had just glossed over that piece of information! The strain-stress effects on band structure is the "physics", and unless you are applying for a research position in which THAT is one of the areas of study for that open position, the potential employer probably cares VERY little about that useless fact.

Instead, what the applicant should have done is say something like "Ability to fabricate metals and semiconductor thin films using MOCVD, producing large epitaxial single crystals. I am also able to analyze these thin films using XRD to evaluate the quality of the thin films". The applicants could also list ALL of the thin film materials that he/she had the ability to make. Now THIS would be something valuable. In doing that, the applicant has revealed the skill that he/she has, and it is a skill that completely transcends any particular subject matter area. This is because the skill to make films using CVD technique is used in MANY different areas, and not just in physics either. Having that skill allows one to apply to a large variety of jobs that would not have been possible if one were to stick to simply the subject matter of one's major area. This is why such skills MUST be clearly and plainly described in one's CV!

Zz.