2025-2026 Edition

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Introduction

The Harvard-Radcliffe Society of Physics Students – SPS for short – has produced this booklet for students who are considering concentrating in physics or a related field. Even if you're not planning to become a physics concentrator, we hope you'll find this booklet helpful.

It can be hard to decide on a field to concentrate in. It's also hard to choose which courses to take, whether they're in the physics department or outside of it. We can't help you with choosing an Expository Writing class, but we hope our experience as physics concentrators at Harvard will be useful to you. You can use this guide during course preview period/pre-registration, but you might want to keep it in a desk drawer for future reference — it might come in handy over the next few semesters. Take the guide out for a walk once in a while, it likes exercise too.

Of course, when you're choosing your concentration and classes, it's a good idea to get as much information as possible. You can obtain advice from the informational meetings held in the Science Center a few days before classes begin, from individual members of the Physics Department Faculty, from the Head Tutors, and from upper-class students. You can find online resources at www.physics.harvard.edu. In fact, we very strongly encourage you to get advice from as many sources as you can. (Of course, since no one reads the Introduction, we'll stress this later on too.)

Every effort has been made to ensure the accuracy and completeness of the information in this booklet. Nevertheless, it may contain inadvertent errors and omissions, so you should be sure to consult the course information in the my.harvard portal and the student handbook subsection *Fields of Concentration* before making any final decisions.

The Society of Physics Students

Our name says it all. The Harvard-Radcliffe Society of Physics Students (SPS) works to promote the interests of physics students at Harvard and Radcliffe.

The SPS organizes many different kinds of activities throughout the year: academic, career-related, and just-for-fun events. To learn about research going on in the various sub-fields of physics and related areas, be sure to attend the Monday lunches at noon with the visiting colloquium speakers (eat nice food, learn a lot) as well as the Wednesday evening talks with Harvard professors as part of Physics 95 (all are welcome; ice cream served). We also host a number of talks about grad schools and careers for those trained in the physical sciences. We expanded our repertoire of engaging events with *Chilloquium* – a cool new forum where we invite speakers to hold talks with undergraduates in a more relaxed and tractable fashion than in your typical colloquium, hence the name. We also like to emphasize the speaker's background and journey through physics for your viewing pleasure.

Keep your eyes out for events such as movie nights, and liquid nitrogen fun. Don't miss our annual nitrogen-frozen pumpkin drop on Halloween. Fanciful ideas such as races across non-Newtonian cornstarch have been proposed.

The SPS functions as a liaison between the community of physics students and the Physics Department. Notably, we started a new mentoring program between graduate students, upperclassmen, and underclassmen to help guide you through your physics career at Harvard. Additionally, the officers of the SPS regularly meet with the chair and undergrad tutors of the department to discuss issues of concern to physics students. We hope all physics students will bring ideas to this process.

The physics undergraduate study serves as a great place to relax, meet up with other physics students, and get to know the Undergraduate Coordinator, Dionne Clarke, whose office is across the hall. Look out for sweet snacks and free food!

Another important function of the SPS is informing physics students of events that may be of interest to them. The SPS has produced this booklet in an effort to ensure that new students are fully informed about the options available to them. There is also an email list, sps-list@lists.fas.harvard.edu, for major SPS and department announcements. If you want to subscribe to the email list, you can visit our website: https://sites.harvard.edu/society-of-physics.

Why Should I Study Physics?

Good question. Well, if you ask any physicist this question, they will probably tell you without hesitation: "It's fun!" Of course, not all of us are destined to become physics faculty. But even if you're not sure if you want to be a physics pro – in fact, even if you're not sure you want to be a physics concentrator – we think you should at least take a few physics classes. Give us the chance to convince you.

If you want to go into any science, knowledge of physics is a valuable tool to have. Not to toot our own horn too much, but physics is the basis for all phenomena in the understandable universe. Having knowledge of the principles behind all the other sciences leads to a deeper understanding and is a way to avoid silly errors. Do you want to be the biologist or inventor whose ideas violate the conservation of energy? Probably not. A firm grounding in physics can only help your work in other fields.

Also, physics is really fun.

Even if you're not sure if you want to go into research at all, knowledge of physics can help you out. As has become more and more clear, the job market of the new millennium is unlike anything we've ever seen before. Sociologist Manuel Castells calls it an Information Age, where the thriving center of the economy is based not only on technology but on *technology for creating even more technology*. Desirable jobs – the kind that pay off Harvard tuition bills – more and more demand rock-solid analytical skills and the ability to understand complex, difficult problems. A physics education is all about that.

A physics education is also fun.

To put it a little bit more concretely, more and more physics students are taking their undergraduate science degrees into the Big Three areas of professional school: medicine, law, and business. Doctors now routinely perform procedures such as "positron emission tomography" and "magnetic resonance imaging." The study and development of artificial joints and organs demand cutting edge materials and biophysics knowledge. As debates over cloning and movie pirating have shown us, new sciences and technologies have also led to all sorts of legal and social quandaries. Scientifically educated lawyers who can intelligently wade through these morasses are becoming a valuable commodity. And as business and industry become ever more technical, the executive who can actually understand their company's function or product is becoming increasingly valuable. If you're the Wall Street type, hedge funds and investment banks are always looking for people with the analytical and mathematical skills to do whatever it is they do down there. And they are willing to pay them lots and lots and lots of money.

The increasingly important role of technology in our everyday lives has also made clear the need for quality science education in our schools, from elementary to high school. A teacher with a solid science background is an immensely valuable resource to a school and to society at large. If you have some physics knowledge under your belt, schools will love you.

Also, physics is really fun.

Basically, we've been saying the same thing in a bunch of ways: physics demands clear logical thinking and strong math skills. Maybe you're not the kind of person who eats Gaussian integrals for breakfast but taking even a few physics classes will help you hone your analytical thinking and problem solving. As a bonus, you'll learn all about the universe that we live in, which it turns out is a lot wackier than it seems at first glance. If you want to learn more about the clever ways physics applies to everyday life, you might think about taking Physics 125. And if you want to know all about the neat stuff going on in the forefront of physics, check out the Physics Department Colloquia (Monday afternoons), or the Wednesday evening lecture series (in conjunction with Physics 95), or drop into a Chilloquium session. And pester your professors or Polaris mentors for advice – they love being bothered!

In conclusion, you should study physics. It's fun!

Ways to Study Physics at Harvard

Harvard is a very exciting place, but it's a bit confusing for the first few weeks. So much happens before you've really figured out where you are! You've probably come with a lot of interests, but you may not be sure how to pursue them here. The Society of Physics Students thought we could help you out a little bit as you get acclimated, by giving you some advice on what you can do with your interest in the physical sciences.

The first thing to realize is that you have many options. Some choices must be made by November of your sophomore year, when you select a concentration. You could concentrate in physics. You may wish to joint concentrate. Or you might take physics classes for a secondary field or as electives, with no thought of concentrating in physics at all. New and different plans of study are constantly being invented, so you should also feel free to dream up just about anything and present it to Prof. Sonia Paban (the Director of Undergraduate Studies) or Dr. Anna Klales (the Associate Director of Undergraduate Studies). Chances are they've heard worse!

(And after all this, you may very likely change your mind about these decisions. No problem—nothing is written in stone!)

If you are considering concentrating in physics (or some variation on that theme), this section describes the myriad options for concentration. More details can be found in the *Fields of Concentration* section of the Student Handbook.

Or you may wish to jump directly to the course descriptions.

The Physics Concentration

Let's start with the most straightforward case. You want to concentrate in physics. (Yay!) For non-honors, you must take twelve semester courses in physics or related fields. These twelve courses normally include the introductory sequence (through a semester of quantum mechanics) and math through multivariable calculus and linear algebra. After that, almost everything you can think of counts either as a physics course or as a related course. So, you can concentrate in physics without actually taking **that** many physics courses. However, if you're sitting here figuring out how few you can get away with, you might be happier in another department.

We're serious when we say twelve semester courses in physics *or related fields*. These related fields' courses might include offerings of the Chemistry, Mathematics, Applied Mathematics, Computer Science, Astronomy, Engineering, Statistics, and other departments. Check them out!

If you're looking for a well-rounded physics education, the honors course requirements serve as a good guideline. (Most people do honors, especially since there's no thesis, tutorial, or general exam requirement; most departments require at least a thesis.) For an honors degree, thirteen to fifteen courses are required, including the introductory sequence, two math courses beyond multivariable and linear algebra, and the advanced laboratory class (Physics 191r). Quantum beyond the first semester and thermodynamics/statistical mechanics courses are highly recommended, especially for those considering graduate work. If you already know single-variable calculus, you may be able to place into a higher math course and reduce the number of courses required for honors to as few as thirteen.

Joint Concentrations

So now that you're taking 50 million classes, what about combining a physics concentration with something else? If you have a very strong interest in another area, you may want to consider a joint concentration (Harvard speak for a double major). Joint concentrations often require the completion of honors requirements in both departments. While this sounds like a gargantuan task, it's usually feasible.

Some fields combine quite naturally with physics. For example, "physics and math" works out to a mere three semesters of math beyond multivariable calculus and linear algebra (including one analysis, one abstract algebra, and one geometry course, i.e., one math course in each of the 110s, 120s, and 130s) among your thirteen courses for the Honors Physics degree. "Physics and Astrophysics" is also easy; just substitute the astrophysics laboratory course for the lab course offered by the Physics Department, and take five semesters of astronomy (16, 17, 98, and two others that count as related courses in Physics).

If that's all you do, you may ask why you should bother to declare a joint concentration. Perhaps most simply, it lets potential employers/graduate schools/significant others know what your real interests are. A joint concentration will also give you greater access to both departments.

Some fields, on the other hand, do not combine with physics quite so naturally. For a joint concentration like Physics and Classics, you'll really have to talk with the Head Tutor of each department. "Negotiate" might be the more appropriate term, but do not despair — with a bit of persistence all things are possible. And such joint concentrations have probably been done before! (You will probably soon learn the story of one dedicated concentrator in Physics and Music and the physics-related musical he wrote. Another student who graduated in 2009 did a special concentration combining physics and theater; her thesis was a play on quantum mechanics!)

Also, a joint concentration in physics is easier than one in many other areas. If both departments require a thesis for an honors degree, then a joint concentrator must write a thesis combining the two fields. Because physics does not require a thesis for honors, only the thesis requirements of the other department apply.

There are a few subtleties to joint concentrations. While the "physics and math" joint concentration does not require a thesis, the "math and physics" concentration does. "Chemistry and Physics" is also a bit different — it is a single concentration blending the two fields, technically *not* a joint concentration. No, it doesn't make much sense, so read the fine print carefully!

Secondary Field

The Faculty of Arts and Sciences offers "Secondary Fields" at Harvard College, which may be thought of as the equivalent to what are called "minors" at other institutions. Amongst the departments offering secondary fields is the Physics Department. Students who decide not to study Physics as their primary concentration and have difficulty "negotiating" a joint concentration with another department should certainly consider this as an option!

The secondary field in Physics requires 4 courses. Students must take one course in electricity and magnetism (usually Physics 15b or 153), one course in wave phenomena and/optics (normally 15c), and one course in quantum mechanics (normally 143a). The final course should simply be a physics course at the 100 level or higher. Of course, students are welcome to take courses of higher level that cover the specified material. Note that although mechanics (normally 15a or 16 or 19) is not required for a secondary field, it is a prerequisite for almost all other physics courses and is strongly recommended.

More information on the details and procedures of this option can be found in the *Handbook for Students* online. Interested students should, as always, consult Prof. Paban or Dr. Klales!

Other Options for Physics Concentrations

Biophysics is great if you have interests in biological questions from a physical standpoint. As a very research-oriented option, coursework is flexible enough for concentrators to continue with classes in the physical sciences, many of which have departmental courses at the intersection with biology. Work in a professor's lab is required instead of the standard physics laboratory course. For more information on working with professors, please see the "Research At Harvard" section.

For the experimentally oriented among you, there is also an Applied Physics option. It combines hands-on physics, the advanced laboratory 191r, and Engineering Sciences classes.

Not Concentrating at All

Maybe you're interested in physics but you'd rather spend most of your time doing something else. Great! You can still take a lot of physics classes. As a first year, there are a few different options of introductory sequences that you can look into: 12a and 12b; and 15a (or 16 or 19), 15b, and 15c. For the life sciences, or if you are interested in medical school, be sure to look into the Physical Sciences 1, 2 and 3. You will typically need to have these classes under your belt to take a higher-level course, but all the requirements are negotiable – just talk to Prof. Paban or Dr. Klales. In particular, we often see math, chemistry, or even computer science concentrators taking quantum mechanics (143a). Certain other classes are not as mathematical as most and are also worth thinking about. More advanced undergraduates in the sciences should be well-qualified to take many 100-level physics classes.

Concurrent Master's Degree

Beyond the different concentration tracks, you may also have the option of getting a master's degree concurrently with your A.B. in four years. Check the Harvard College website for eligibility requirements, as the rules have recently changed. An extremely challenging course load is necessary to satisfy the requirements, so very few students pursue this option.

When pursuing the A.M., you continue to live as an undergraduate for four years and can fulfill the requirements with classes taken at any point during your college career. The A.M. requirements typically consist of eight classes, with at least six being grad classes and at least four being physics. Chem/Phys concentrators may also want to consider the A.M. in Chemistry or the S.M. in Applied Physics.. Talk to upper-class students and Prof. Paban or Dr. Klales for more information.

Physics Course Strategies

We can't be sure that this advice will be useful to everyone, but if you learn the same way most of us do, these hints may help your physics career run more smoothly. Here are some general strategies that many of us wish we had learned sooner.

• **Talk to other students!**

Upper-class students are the most valuable source of information about *anything* at Harvard. They can tell you about courses, professors, research opportunities, summer programs, ways around bureaucratic obstacles, where the party's at — in short, how to get the most out of your Harvard experience. If the people you talk to don't know the answer to your question, chances are they know someone else who does.

Self-promotion time: coming to SPS events is a great way to meet older physics concentrators (and people who like physics, or people who like people who like physics). The first few SPS events focus heavily on course advising and getting to know older physics concentrators. You should also feel free to contact the SPS officers at any time; see the back cover for contact information. There is of course plenty of free advice (and addictive food) to be had at SPS events, but you should also take advantage of the other opportunities/people available to you.

• **Look into classes with your omnipotent friend Q**

If you go to the COOP a few days before classes, you should have a chance to look at the text for each class. Look at the first chapter. How do you feel? Now open the book to the middle. Excited? Great! Also, for both physics and non-physics courses, consult the *Q-Guide* to see how students have rated the course in the past. Note, however, that the professor for the course may have changed; the *Q-Guide* will point you to another course they have taught if possible. Take this information into account! The professor makes the course!!! Check the online *Q-Guide* for ratings from previous years: https://qreports.fas.harvard.edu/.

• **Take advantage of shopping period**

The surest way to assess a course and its professor is to attend the lectures during shopping period (the first week of classes). Be sure to grab a syllabus. This is your chance to check out all the courses you're considering — and you should look at more courses than you plan to take. Even if you think you already know what you're taking, shop around. You may discover a wonderful class you never even knew about, or you can get a glimpse of courses you may take in the future. Science classes generally dive right into material, so be prepared to take notes and have a way to copy them once you finalize your course selections. Don't take a class you don't enjoy in the first few lectures. Studies have shown that initial impressions of Harvard classes are almost always correct.

• **Get the best section leader**

In most physics courses you won't be required to attend section, but we feel that a good section can greatly enhance your experience. If you are dissatisfied with your assigned section, don't just stay home; find the section most worthwhile for you. If you're required to attend a particular section with which you are unhappy, keep in mind that a "schedule conflict" could make a section change necessary.

Just because a section is optional doesn't mean it's useless — attending section helps reinforce the material you're learning, demonstrates how to work college-level problems, and gives you an opportunity to ask questions about points that confuse you. Plus, a TF who sees you regularly in section may be friendlier when you come to ask her for help on your problem set. It's also good to get to know grad students: they can be very cool people, and they will also expose you to the kind of life that you might live for the next 5-10 years, should you continue in physics. They can also introduce you to their own research and their professors and tell you where to find free food.

• **Go to your professors' office hours!**

Remember when you were thinking about going to Harvard and everyone warned you that you would never have any contact with professors? This is your big chance to prove them wrong! You can use professors' office hours to get help with difficult course material, find out about their research, or discover that they have lives outside physics. You *will* have to go out of your way to seriously interact with most professors, but most will be delighted to see you at their office hours — don't be intimidated! Several lonely professors have been overheard begging students to visit their office hours.

• **Use the Undergraduate Physics Study and the Physics Reading Room**

The Undergraduate Physics Study (Jefferson 251) is an area specifically reserved for undergraduates to work, relax, and chat with friends. The study is right next to the offices of Dr. Klales, the Co-Head Tutor, and Dionne Clarke, the

Undergraduate Coordinator. Look for SPS events, TF office hours, and free food here!

Located on the fourth floor of Jefferson Laboratory, the Physics Reading Room (also known as the Physics Library) is one of the most pleasant places to work or relax on campus. The library is open 24-hours – no swipe access needed. This space is open to the entire physics community, whether you want to do research, work on a problem set, or read the newspaper. And don't forget the cookies every Monday afternoon before the departmental colloquia – they can be found here. Likewise for the many afternoon snack breaks.

• **Work with other people on problem sets!**

We cannot emphasize enough the importance of this. On a practical level, a study group will make your life easier on problem set night and help you understand the material more fully. More importantly, you'll meet and get to know your fellow concentrators. If you're taking a class aimed at physics concentrators, **check out the Physics Library on Wednesday nights – it is where many students, especially those in the intro classes, do their problem sets, in a celebrated weekly tradition known as Physics Night** (the same goes for Math Night on Monday nights). There are always substantial supplies of baked goods available to fuel this endeavor. The Physics Library is usually chock-full of physics concentrators until the wee hours of the morning. Nights in Jefferson usually end up being one of the best parts of being a physics concentrator at Harvard.

If you're going to work with other students outside Physics Night, assembling a study group might take some persistence. But don't be shy about asking people to work with you. If you can't find a study group, reach out to your professor – they should be able to connect you with other students. Also try Facebooking, Instagram messaging, or making a GroupMe with the people in your classes (no it's not sketchy, and yes, it really works), or come to SPS meetings to meet other people in your classes.

We feel obligated to warn you: don't rely on your study group as a crutch — copying answers for problem sets won't help on the exam. And it is technically academic dishonesty and could get you in trouble. We hope that you'll find that your fellow students are more valuable as teachers than as sources of answers.

• **Check out previous final exams.**

Recent exams are often posted on course webpages. Studying problems from old exams is a great way to prepare for your own final. However, beware that if the professor for the class has changed, the final may be entirely different.

Course Descriptions and Recommendations

We are only providing brief course descriptions here since you can look up more detailed descriptions in the my.harvard portal. However, we've also offered some opinions that you won't find in the official descriptions. Just remember that these are our opinions; yours may differ. Also, the prerequisites listed in the course guide are not always up-to-date. Check with the professor if you are considering not following them, however. The prerequisites listed below are also our opinions.

Due to editorial constraints (i.e. the Physics Department gives us money) we are unable to rate professors as well as courses. You should be aware, however, that in many cases **the satisfaction one gains from a class has more to do with the professor who is teaching it than the course material itself**. The *Q-Guide* is an excellent resource for professor ratings. If you wish to find professor ratings from previous years, back issues of the *Q-Guide* can be found at https://qreports.fas.harvard.edu/.

Students who have taken the course provide an even better source of information. (Always feel free to badger your Polaris mentor or the SPS officers about such things; we've certainly done our share of asking for info!) **We can't emphasize this strongly enough:**

Ask around about professors and courses!!

Also, the professors themselves are good source of information. You might want to talk to them, to watch them in action during shopping period, or both. We suggest that if you are unsure of which course is right for you, talk with the professor giving the course.

If you think you may be familiar with the material in a course, check out the past course webpages and final exams. Take a look at these to get an idea of the level of the course. Even better, find out when this year's professor last gave the course, and check the final exams from that year, available at the Gordon McKay Library of Engineering and Applied Sciences.

Below we have included all undergraduate courses offered by the Physics Department, and many courses in the related fields. The rest you might just want to mull over for a while. (Or, as Nobel Laureate Leon Lederman said: "Put your nose to the glass and look at all the candy!")

Not all of the courses listed are taught in any given year. Please check my.harvard for the official schedule. Those marked by an asterisk (*) are

courses you should especially consider during your first year. Courses demarcated with [brackets] will probably not be offered this year, but again, check my.harvard for the official list.

Freshman Seminars

Freshman seminars are very different from most other courses you will take in your first year. In these courses, a small group of students works closely with a professor in the investigation of a field—there is a great deal of informal interaction in addition to standard classroom fare.

A freshman seminar can supplement the introductory sequence (see below) if you think you may concentrate in physics; it can also be a great way of dabbling in physics if you're sure you won't concentrate in it. The only good reason not to take a seminar is time. These courses are electives. If it's important to you to get started on the introductory sequences in physics, math, and chemistry all at once, then you might not have time for a freshman seminar. Still, don't discount the option without some thought; a freshman seminar (inside or outside your field) can be one of your best academic experiences at Harvard.

We heartily recommend considering a freshman seminar in any area that piques your interest; here we list those related to physics. Also consider taking a freshman seminar not in physics – it's a great way to expand your interests. Note that there are many seminars not listed here related to the other sciences as well.

[**Freshman Seminar 21G (Loeb)**: Genesis of Stars and Life in the Cosmos (Spring)]*

* **Freshman Seminar 21V (Strominger):** Black Holes, String Theory, and the Fundamental Laws of Nature (Fall)

** **Freshman Seminar 22I (Bloxham):** The Science of Sailing (Fall)*

* **Freshman Seminar 23C (Woodin)**: Exploring the Infinite (Fall)

* **Freshman Seminar 23P (Vafa)**: Physics, Math and Puzzles (Fall)

This seminar is intensely rewarding for students interested in physics, mathematics, and the interface between the two. Simple yet profound results in physics are explored through the unique medium of puzzle-solving. Consider this puzzle: There are four cities at the corners of a square. You have to build roads so that you can drive from any city to any another in some way. How do you do it using the minimum length of road? The answer has to do with why particles have mass. The ideas explored in this class, including symmetries and duality relations, will come up over and over in future physics classes. The light workload of an interesting puzzle to think about each week makes the class an ideal addition for a busy schedule.

** **Freshman Seminar 23R (Alcock)**: Asteroids and Comets (Spring)*

[**Freshman Seminar 23Y (Doyle)**: All Physics in 13 Days (Fall)]*

* **Freshman Seminar 26J (Randall)**: The Universe's Hidden Dimensions (Fall)

*[** **Freshman Seminar 50Y (Huth):** A Sense of Space (and Time)*]*

** **Freshman Seminar 51C (Meade):** Science in the Age of Artificial Intelligence (Fall)*

*[** **Freshman Seminar 51H (Zipser)**: Models of the World: Explaining the Past and Predicting the Future (Fall)*]*

[**Freshman Seminar 51T (Dvorkin)**: The Universe: Its Origin, Evolution, and Major Puzzles (Spring)]*

** **Freshman Seminar 51V (Kim)**: Physics of Measurements: Experimental Science (Fall)*

* **Freshman Seminar 51X (Samuel)**: Changing Perspectives: the Science of Optics in the Visual Arts (Spring)

[**Freshman Seminar 51Z (Finkbeiner)**: The Path to a Low-Carbon Future (Fall)]*

[**Freshman Seminar 52D (Vishwanath)**: Quantum Entanglement and the Second Quantum Revolution (Fall)]*

* **Freshman Seminar 52E (Park)**: Science and Technology Primer for Future Leaders (Spring)

[**Freshman Seminar 52H (Franklin)**: The Interaction of Light with the World (Spring)]*

Seminars require an application and, occasionally, an interview, but are well worth the effort. More information and a complete listing of seminars are available here: https://freshmanseminars.college.harvard.edu/seminars.

Physics Department Courses

Introductory Courses

Physical Science Courses:

* **Physical Sciences 1, 2, 3**: an introduction to the physical sciences for biological applications (1,3 Spring; 2 Fall)

These are the introductory courses to physics as well as physical chemistry with an emphasis on biological applications. They are intended especially for pre-med students but are also recommended for any students who are interested in the physical sciences but do not have much background (though AP Chem is helpful). Among other things, Physical Sciences 1 (PS1) covers introductory general and physical chemistry, while PS2 and PS3 cover mechanics and electromagnetism, respectively. Note that PS2 and PS3 are not accepted for credit towards a physics concentration, though they are accepted for other concentrations, such as chemistry. Students should consult the department for more information.

* **Chem 10 (formerly Physical Sciences 10)**: Quantum, Statistical, and Computational Foundations of Chemistry (Fall)

* **Physical Sciences 11**: Foundations and Frontiers of Modern Chemistry: A Molecular and Global Perspective (Spring)

These courses, besides your typical introductory general chemistry material, intend to introduce fields and applications that you might not get to outside of more advanced physics and chemistry classes. Chem 10, for instance, goes over the fundamentals of quantum mechanics and statistical mechanics, while PS11 looks at topics such as thermodynamics and quantum chemistry (overlapping topics with PS1 as well). Both emphasize real-world applications, such as medical imaging, global warming, and electric cars. These courses can also be taken independently of each other. Pre-med general chemistry requirements can be fulfilled with any two courses from Life and Physical Sciences A, Life Sciences 1a, PS1, PS10, and PS11. Students should consult the department for more information.

* **Physical Sciences 12a, b**: Mechanics (Spring) and Electromagnetism and Statistical Physics (Fall) from an Analytic, Numerical, and Experimental Perspective

These courses comprise a standard college-level one-year introduction to physics, with emphasis on engineering applications and experimental data analysis. They satisfy medical school requirements and are highly recommended for a pre-med concentrating in an area other than physics but looking for a more rigorous treatment than PS2 and PS3. PS 12a, b is accepted for credit in many concentrations, including chemistry and engineering. If you wish to count PS 12a, b toward the Physics or Chem/Phys concentrations, be sure to consult the department to develop a coherent plan of study.

* **Applied Physics 50a, b**: Physics as a Foundation for Science and Engineering

These courses form a unique year-long project-based introduction to physics. They are relatively new and promise to provide the equivalent of a standard introductory physics course, but with a heavy emphasis on engineering-inspired group projects. Math at the level of Math 1b concurrently is required, though it's recommended to take Math or Applied Math 21a concurrently; math content will be coordinated with AM 21a. Consult the department for more information.

Physics Courses:

* **Physics 15a**: Introductory Mechanics and Relativity (Fall and Spring)

* **Physics 16:** Mechanics and Special Relativity (Fall)

* **Physics 19:** Introduction to Theoretical Physics

Ah, the great first-year dilemma. Physics 15a, 16, and 19 are your choices for your first physics class as a physics concentrator – you can take any one of the three; they all feed into the same sequence (15a/16/19, 15b, 15c, 143a). Basically, 15a and 19 are hard, while 16 is **very** hard. They all go beyond the high school AP Physics level and introduce all sorts of interesting topics. Many freshmen are not sure whether they will be able to handle 16. Fortunately, the Department makes it easy to switch between courses at the beginning of the semester once you get a feel for them. You probably want to take a look at 16, but **don't feel obligated to take it**. Depending on what you took in high school, it might be a better idea to hone your math background first – 16 is very demanding mathematically. **And if you're planning on taking other difficult classes, there's no point in killing yourself with work.** On the other hand, Physics 16 is a trial-by-fire bonding experience for those who take it. Many who take it call it one of the standout experiences of their Harvard career.

Phys 19 covers a wider set of foundational topics for theoretical physics than

15a or 16, but covers mechanics in less depth, and is intended to give a broader preview of later courses in the physics concentration. Phys 19 is designed to accommodate a wide range of backgrounds and interests: it assumes only a familiarity with single-variable calculus and teaches the necessary mathematical background along the way. Since the course structure consists of problem sets and a final project, there are plenty of opportunities for those that wish to engage deeply with the material to further enrich their understanding; for those that are just interested in a taste of a bit of everything, Phys 19 has a place for you too.

The main point of 15a and 16 is to learn mechanics and solve challenging problems simply because physics is cool. The main point of Phys 19 is to provide a comprehensive grounding and experience in the concepts and mathematical tools of theoretical physics that show up in the rest of the physics concentration. But also because physics is cool.

For 15a, concurrent enrollment in Math 1b is required (with 21a recommended), while for 16 concurrent enrollment in Math 21a or an equivalent is required: most students in 16 last year took one of Math 22/25/55. And by the way, we also recommend 15a for non-concentrators who wish to take physics and come out with a fairly deep understanding of mechanics (many chemistry and engineering concentrators choose this option).

* **Physics 15b**: Introductory Electromagnetism (Fall and Spring)

Physics 15b covers electricity and magnetism **at a level significantly beyond AP,** and follows 15a/16/19 in the introductory sequence. Non-concentrators will often take the class, leading to a wide range in students' experience. However, the course is flexible and provides plenty of support or challenge no matter what your physics background. Math 21a is a formal corequisite; however, we recommend a multivariable background coming into the course.

A few students each year consider skipping 15b to take 153 (Electrodynamics). Consult with Prof. Paban and think long and deeply before deciding. Remember that the PSI lab for 15b is still required of all concentrators.

Physics 15c: Wave Phenomena (Fall and Spring)

This is a course in waves and optics. It covers important material for future courses, including the wave equation, Fourier analysis, and a formal introduction to oscillations. Oscillations are the basis of quantum mechanics, and 15c will provide powerful tools for future physics courses (even if balls on springs and pendula seem boring to you now). Math 21b is a corequisite.

Most of those taking this course are physics (or astronomy) concentrators, though some chemists interested in physical chemistry take it as well. There are also still plenty of people there for interest's sake, and we encourage non-concentrators who have the time to get at least this far.

Note that this course, more so than 15a and 15b, can be a noticeably different experience under different professors who may take different approaches or cover different topics. Ask around and check the Q Guide for opinions. If you are considering taking Physics 175 or another course to fulfill the 15c requirement, consult with Prof. Paban and think carefully before making this decision. Remember, the PSI lab for 15c is still required for all concentrators.

Physics 20/Applied Math 10: Computing with Python for Scientists and Engineers (Fall)

This course is a systematic introduction to computing (with python and jupyter notebooks) for science and engineering applications. Applications are drawn from a broad range of disciplines, including physical, financial, and biological-epidemiological problems. The course consists of two parts: 1. Basics: essential elements of computing, including types of variables, lists, arrays, iteration and control flow (for, while loops, if statement), definition of functions, recursion, file handling and simple plots, plotting and visualization tools in higher dimensions. 2. Applications: development of computational skills for problem solving, including numerical and machine learning methods, and their use in deterministic and stochastic approaches; examples include numerical differentiation and integration, fitting of curves and error analysis, solution of simple differential equations, random numbers and stochastic sampling, and advanced methods like neural networks and simulated annealing for optimization in complex systems. Course work consists of attending lectures and labs, weekly homework assignments, a mid-term project and a final project; while work is developed collaboratively, coding assignments are submitted individually.

Physical Sciences 70: Introduction to Digital Fabrication (Fall and Spring)

An immersive introduction to rapid prototyping, fusing physics, design, computer science, engineering, and art. Students will learn to safely use software and hardware to fabricate programmable projects. Tools and topics will include programmable microcontrollers, 3D CAD/CAM, electronic circuit design, and wireless networking (Internet of Things). Additionally, students will learn operational principles for techniques such as laser cutting, 3D printing, and computer-controlled milling. The course will culminate with an individual final project of the student's own conception, integrating as many of the weekly topics as possible. The course emphasizes self-directed learning and supports students in accessing resources to help advance the development of their unique projects. Applications may include personal fabrication, product prototyping, fine arts, and the creation of scientific research tools. Students will document work on each weekly topic in a personal website, thereby finishing the course with an online portfolio that not only illustrates their new skill sets, but also contributes to a collective repository of knowledge that serves as a foundation for continued learning.

Physics 143a: Quantum Mechanics I (Fall and Spring)

Ah, quantum mechanics. As Prof. John Doyle puts it, "this class is what separates physicists from everyone else." This course is required of all concentrators and is a prerequisite for most of the cool upper-level physics courses. Physics 15c is a prerequisite (although every year a few students with a strong background skip 15c). Math 21b is also a definite prerequisite; we feel that the more linear algebra you know, the better you will understand the material. (Math 22a, 25a, or 121 will make this course even more worthwhile!) If, by the time you are ready to take 15c, you are already strong in linear algebra, Fourier Analysis, and understand the wave equation, you may consider taking 143a concurrently with 15c, **but** having previously taken 15c makes 143a much, much more comprehensible. Taking 151 (Mechanics) before this class also helps, especially with Hamiltonians, although not many concentrators go that route, and Hamiltonians aren't difficult to pick up during 143a.

Concentrators in other sciences often take this course, especially chemists as an alternative to the quantum course in the chemistry department. The course will have a very different flavor from Chem 160, so consider this decision carefully.

The above introductory physics courses are offered every semester (except Physics 16 and 19, which are only offered in the fall), so if you think that you don't want to start right in (though we can't imagine why you wouldn't) but later have a change of heart, you don't need to spend a whole semester twiddling your thumbs and waiting for the intro course you want to take. If you do take your physics classes "out of phase," they will be smaller and may have a different set of professors. But once you finish 143a, you'll be back in sync with the rest of the concentrators.

Courses Beyond the Introductory Sequence

Physics 125: Widely Applied Physics (Fall)

This course uses physics to analyze important technologies and real world systems; it emphasizes physical intuition and order-of-magnitude calculations. It aims to develop a toolbox that all physicists should have at their fingertips. The 15a/b/c series is a prerequisite, with 143a recommended at least as a concurrent course. The material covered in this course varies greatly depending on the instructor.

Physics 129: Energy Science (Spring)

Consult the department for more information.

Physics 137: Philosophy of Quantum Theory (Spring)

This course digs into the philosophical framework of quantum theory. Cross-listed as Philosophy 151, it fulfills either a Science & Engineering or Arts & Humanities distribution requirement depending on how you enroll. It also counts as a physics elective. There are no exams. Expect weekly reading assignments, psets which include both mathematical exercises and more formal philosophical essays, and a short final paper. This is a small seminar-style class with an enthusiastic, friendly professor (Jacob Barandes). If you're interested in reading original source materials and engaging in lively discussions blending physics and philosophy, then this course is for you. However, this course does not require the same mathematical rigor as 143a – while only algebra is required, a background in calculus and linear is helpful.

Physics 141: The Physics of Sensory Systems in Biology (Fall)

Consult the department for more information.

Physics 143b: Quantum Mechanics II (Fall and Spring)

This course takes what you learned in 143a and uses it to study all kinds of physical systems. The exact details of what is covered vary from year to year, but they generally involve atomic systems and approximations. You won't learn much more about fundamental quantum theory in 143b; the main developments are different ways to approximate various situations to make them amenable to solution by quantum mechanical means.

However, keep in mind that 143b covers some basic material physicists are expected to know and that you might not get in any other class; atomic and molecular physics are fundamental applications of quantum mechanics. Physics 143b will not only firm up what you learned in 143a, but it also opens the doors to many modern fields of research, like condensed matter physics, quantum information, and AMO theory. It may be a little tedious for some, but you'll be a better physicist for it – and it's critical for grad school. For all the Chem/Phys students out there, keep in mind that this is the class in which you'll learn why elements, atoms, and molecules work the way they do. And often the last week is an introduction to quantum computing. Interested? Awesome!

Physics 145: Elementary Particle Physics (Fall)

Elementary particle physics is a large and difficult area that requires a great deal of mathematical and physical preparation to understand fully. Most students never see much of the theory until graduate school. This course successfully remedies that situation by focusing on intuitive understanding of the concepts involved rather than the calculational aspects.

This is usually a small class, with a greater opportunity for interaction with the professor both in and out of the classroom. A fun and rewarding course that is highly recommended!

Physics 151: Mechanics (Fall)

This course studies mechanics from a more advanced point of view than 15a or 16, starting with the Lagrangian formulation. However, once you get past Lagrange's and Hamilton's equations, there is a lot of time left over, and the course seems to vary greatly with the idiosyncrasies of its instructors. Because of this, we suggest that you do some research before taking this course, to find out what the instructor plans to cover. Many concentrators choose to skip this class because the math can get dense, but classical mechanics can be pretty interesting. Taking this course concurrently with 15c is a great way to prepare for 143a, which will involve lots and lots of Hamiltonians. Oftentimes, this course covers topics like classical field theory and forays into the connection between classical and quantum mechanics via discussions of the Feynman path integral. These topics are especially important for budding theorists!

Physics 153: Electrodynamics (Spring)

Physics 153 is an intermediate course in electrodynamics. It reconsiders the non-electronics material of 15b with greater mathematical sophistication and overall depth. Prior understanding of concepts from electricity and magnetism are assumed, however, so we do not normally recommend skipping 15b to take 153 (certain topics, such as circuits, are not covered in 153; hence the asterisk on the asterisk). Some professors also spend part of the course covering important mathematical techniques (e.g. Bessel functions). Some students are particularly happy with David Griffiths' *Introductory Electrodynamics*, which is typically the text for this course.

Physics 160: Introduction to Quantum Information Science (Fall)

This is a new course first offered in Fall 2025. Consult department for more information.

Physics 175: Laser Physics and Modern Optical Physics (Spring)

Introduction to quantum electronics (laser physics) and modern optical physics aimed at advanced undergraduates, with an emphasis on applications. This course is often taught by Marcus Greiner who brings a superlative experimental perspective (and sweet demos too) to the course.

Physics 181: Statistical Mechanics and Thermodynamics (Spring)

For perhaps the first time in physics, you'll be looking at not one-body, not two-body, but 10^{23}-body systems! This course, or Engineering Sciences 181 or Chemistry 161, is strongly recommended for concentrators at some point. You really can't get by as a physicist without knowing something about this stuff. The Physics Department course is more geared towards statistical mechanics, while the ES course emphasizes thermodynamics. Chemistry 161 covers much of the same material, but with a focus on applications to chemistry. Physics 143a is a prerequisite.

Physics 195: Introduction to Solid State Physics (Fall)

Get ready to apply your newly gained quantum and statistical mechanics skills to a very important system: Solids! Starting with the classical Drude theory of metals, the course aims to derive the electronic and thermal properties of metals, insulators and semiconductors by applying quantum mechanics to periodic systems. It is an essential course for research in condensed matter physics! This course is typically jointly offered as Applied Physics 195.

Applied Physics 195: Introduction to Solid State Physics (Fall)

The same class as Physics 195, but jointly listed through SEAS.

Laboratory Courses

Physics 113: Electronics for Physicists (Fall and Spring)

This class is a great option to take. It's heavily lab/building–based, with less emphasis on lectures and assignments, and contains a wide range of interesting content from PID control and Arduino programming to signal processing and filtering techniques. The grading isn't too stressful either, as the exams also involve a lab/circuit construction component. Overall, would recommend for anyone interested in laboratory circuitry, general circuitry principles, signal processing basics, Arduino, etc.

* **Physics 123**: Laboratory Electronics (Fall and Spring)

This course in laboratory electronics presents the skills needed to construct scientific instruments, a valuable ability for those wanting to go into experimental physics or just those wanting to leave Harvard actually being able to do something useful. The broad introduction to analog and digital electronics is also valuable for engineering concentrators and some Computer Science concentrators; both undergrads and grad students take the class. There are no formal prerequisites, but at least high school physics and some familiarity with calculus is useful. Previous experience with basic electronics or low-level programming can be immensely useful. Engineering Sciences 151, 154 and 156 cover similar topics, but the physics course is more focused on "seat-of-the-pants" electronic design emphasizing broad understanding over calculational proficiency. As might be expected, the class requires a substantial time commitment, but you get out of it everything you put in. Estimates of workload range from 1.5 to 2.5 normal classes.

Physics 191: Advanced Laboratory

In this laboratory course, required of all *honors* concentrators (and highly recommended for all concentrators), students carry out three experiments chosen from a list. These are not your basic high school measure-*g*-with-a-pendulum-and-stopwatch experiments: topics include superfluid helium, the lifetime of the m-meson, and Nuclear Magnetic Resonance. Physics 15abc is required, and 143a is highly recommended. The actual knowledge needed for these courses is highly dependent on the experiments performed; some experiments make more sense if you've also taken 181. If you are leaning towards Astrophysics (and have taken enough courses in that department), talk to the head tutors about the possibility of taking Astronomy 191 instead.

The 90's: Research, Reading, and Ice Cream

Physics 90r/91r: Supervised Research/Reading (Fall and Spring)

These two courses allow students to pursue research or reading in areas of physics not covered in the curriculum or in which more in-depth knowledge is wanted. They are very valuable for those who think they may wish to pursue physics after their undergraduate years. Since the subject matter can be anything, so can the prerequisites. See the section on research for hints on figuring out what to study. These courses sometimes culminate in a senior thesis. Do not hesitate to reach out to professors to discuss the possibility of pursuing supervised reading or research! Many students find this experience incredibly helpful.

Physics 95: Topics in Current Research (Fall and Spring)

Physics 95 is first and foremost a course in science communication, with an emphasis on upperclass-level physics. The centerpiece of the class is the three 20-minute oral presentations that each student is required to give throughout the semester; individual attention is given by the professor in this seminar-style course to every student's presenting skills, ensuring that you walk away with a clear understanding of how to get in front of people and give an engaging, comprehensible talk about any subject.

Directed toward juniors and seniors, this course offers a wider variety of topics to titillate the imagination. The course is complemented by weekly Wednesday evening lectures by different Harvard professors; each professor discusses their ongoing research, and free post-lecture ice cream is served every week. (These evening lectures are open to all physics students, not just the enrollees in Phys 95!) This course is an excellent opportunity to learn about the ongoing research interests of the faculty, to develop effective communication skills as a scientist, and to follow up on one research topic from lecture in the required final project.

Graduate Courses

Some undergraduates in the past, usually after completing the corresponding 100-level course, have ventured on into the realm of graduate courses. These are often very different from undergraduate courses due to the differing needs of their students, and typically they represent quite a significant workload. That disclaimer aside, here are a few graduate courses highly advanced undergraduates have taken with success.

Physics 210: General Theory of Relativity (Spring)

General relativity is the final course a student takes in classical theory. Curved spacetime, black holes, an expanding universe, the whole nine yards. Physics 210 is not a prerequisite for many other courses aside from Physics 211r; it is an end in itself. The mathematical tools required, such as familiarity with tensors and differential geometry, are developed naturally as the course progresses. However, it may take a while to get to the actual physics of the class. Long, tedious calculations of quantities involving rank-4 tensors are a staple of the coursework - so be prepared. All the effort is worth it in the end, as the course provides a great introduction to general relativity.

Physics 232: Advanced Classical Electromagnetism (Spring)

This course definitely requires some sort of previous background in electromagnetism, ideally at the advanced undergraduate level of Physics 153. The syllabus begins with relativity and quantum mechanics and explains the fundamental underpinnings of Maxwell's Equations before going through a more traditional EM curriculum, often from J.D. Jackson's classic textbook, to end up anywhere from magnetic monopoles to non-abelian gauge theories to superconductivity. This is a great course for learning about electromagnetism in depth. Be aware, though, that the material covered in the latter parts of the course may vary greatly depending on the professor.

Physics 251a/b: Advanced Quantum Mechanics I/II (a Fall, b Spring)

As the introductory quantum sequence for graduate students, Physics 251a/b offer an advanced, fresh beginning for quantum mechanics. Starting from scratch, the class clarifies the mathematical and physical foundations of quantum theory. Instructors vary in pace and material, but typically the class moves quickly and the lectures are at a high level. Students who have completed the 143a/b sequence and are interested in strengthening their quantum mechanics foundations should keep these classes on their radar.

Physics 253a: Quantum Field Theory I (Fall)

Physics 253a is the first course in the graduate quantum field theory sequence. You will want to take a quantum field theory course at some point in your career if you are interested in high-energy physics, nuclear physics, or condensed matter physics, and it is nice to have some understanding of the subject if you intend to continue your studies in physics at the graduate level. While it is a very advanced course, you can probably handle it if you have taken at least Physics 143a and 143b. Physics 151 might also be helpful to gain a grounding in classical field theory, but it is not strictly necessary as the course typically starts with a fast-paced introduction. The course is often taught by Prof. Matthew Schwartz, whose celebrated textbook *Quantum Field Theory and the Standard Model* provides a good introduction to the subject and is usually the text of choice for the class. The problem sets will require a very significant time commitment, however, and you should bear in mind that Physics 253a is not a great addition to an already crowded schedule. Quantum Field Theory is an incredibly vast subject, so while this course offers a very solid introduction to the field (Chapters 1-19 of Prof. Schwartz's textbook), keep in mind that there is much more to come. Also note that while MIT has a 3-semester QFT series just like Harvard, Harvard's version covers significantly more material in a shorter amount of time.

Physics 253b: Quantum Field Theory II (Spring)

The second of Harvard's 3-semester QFT series, this course starts where Physics 253a leaves off and turns the difficulty up tenfold. It covers the remaining chapters of Prof. Schwartz's textbook as well as a large chunk of Weinberg's second volume. Taking this course on its own will have you working harder than most of your peers, so only consider it if you are sure you want to do high energy or condensed matter theory. You may also want to consider Physics 254 when it's offered as a good, less extreme alternative.

***[Physics 253c**: Quantum Field Theory III (Fall)]*

The third of Harvard's 3-semester QFT series, this is a topics course which covers different material based on when it is being taught. This course is a very exciting gem once you've taken Physics 253a, and may cover topics such as supersymmetry or conformal field theory.

Physics 254: The Standard Model (Spring)

An amazing sequel to Physics 253a, this course puts the material you learned in Physics 253a to good use by introducing the building blocks of the Standard

Model. If you ever wanted to go beyond the Quantum Electrodynamics from Physics 253a, and learn about the weak and strong forces, as well as the Higgs Mechanism, this is the course you're looking for. While you can take it along with Physics 253b, students usually take one or the other.

Physics 260: Introduction to Quantum Information (Spring)

This course will offer an introduction to some fundamental concepts in quantum information, quantum algorithms, and quantum error correction. The focus will be to elucidate the nature of entanglement and its manipulation, framework for building quantum algorithms, methods for quantum error correction, the entropic view on various aspects of quantum information and various implementation models. The topics covered will be basics of quantum information (entanglement, quantum teleportation, Pauli operators), models of quantum computing (quantum circuits, quantum channels), fundamental quantum algorithms (Quantum Fourier transform, Quantum phase estimation, Grover's search, Quantum walks), and quantum error correction (Stabilizer codes, fault tolerant quantum computing).

Physics 262/Applied Physics 284: Graduate Statistical Mechanics

This class is an ambitious survey of the vast and integral field of statistical mechanics. When taught by Prof. Manoharan, the class touches upon various aspects of Physics 181 (except for thermodynamics) in a slightly more sophisticated manner, before tackling essential concepts in statistical physics such as the Ising model, universality & scaling, and renormalization group, all in a physically intuitively albeit not intimidatingly technical manner. While the class has some shortcomings in terms of rigor, a result of the necessarily ambitious scope of the class, it is an extremely cogent advanced introduction to statistical physics and develops intuition that is useful in various quantitative fields outside of physics as well. A very reasonable option, perhaps best taken after Physics 181, that is challenging but ultimately very approachable for motivated undergraduates.

Physics 271: Topics in the Physics of Quantum Information (Fall)

This course is especially helpful for students who have already taken Physics 175 and are considering research or graduate school in quantum information.

Physics 285a: Modern Atomic and Optical Physics I (Spring)

This course is especially helpful for students who have already taken Physics 175 and are considering research or graduate school in atomic, molecular, and optical physics.

Physics/Applied Physics 295a: Intro to Quantum Theory of Solids (Fall)

This course is especially helpful for students who have already taken Physics 195 and are considering research or graduate school in condensed matter physics.

Mathematics Department Courses

Part of being a physicist is learning a lot of math, whether you want to or not. So here's a brief outline of the math classes you'll probably be encountering soon. More detailed information on these and other courses in mathematics may be found in *Mathematical Sciences at Harvard*, available from the Mathematics Department. You can also check out the Applied Mathematics and Statistics Departments for more math and related courses. Another useful source is *A Student Perspective on the Math Department*, an unofficial guide put together by Gender Inclusivity in Mathematics.

All freshmen take a math placement exam in June before their freshman year. This exam may place students in any of the pre-calculus and first year calculus courses, or it may indicate Math 21a. (If you are placed in Math 21a, *any* of the multivariable calculus courses may be appropriate for you.) However, students should remember that this placement exam, while a guideline, is only that: a guideline. If you feel you have been misplaced, you are ultimately free to decide for yourself.

Pre-calculus and First Year Calculus Courses

* **Math Ma, b**: Introduction to Functions and Calculus

This is a pre-calculus and introductory calculus sequence for those not quite ready to jump into Math 1a. Applications are emphasized. Unfortunately, it is very difficult to concentrate in physics if one begins math with these courses.

* **Math 1a, b**: Introduction to Calculus

These courses are a first-year study of calculus. A few physics concentrators begin math in one of these two courses; however, the large number of prerequisites for many physics courses gives these students fewer choices in their later schedules.

Multivariable Calculus and Linear Algebra

* **Math 21a, b**: Multivariable Calculus; Linear Algebra and Differential Equations (Fall and Spring)

Math 21a presents multivariable calculus. It is appropriate for students who have completed Math 1b or received a 4 or 5 on the AP Calculus BC exam. Math 21b is a course in linear algebra and beginning differential equations. Though most people take 21a and 21b in that order, the courses can actually be taken the other way around too. Most physics concentrators begin math in 21a. Very few skip these courses; if a more theoretical perspective is desired, Math 23, 25, or 55 may be more appropriate, but 21 will give you the most knowledge you need for early physics classes. A multivariable calculus sequence (21, 22, 25, or 55) is a prerequisite for most 100-level math or physics courses.

Note that although you are assigned a particular section for the 21a, b sequence, it is important to have a good section leader. Therefore, there is some "flexibility" in "picking" the section you attend.

* **Applied Math 22a, b**: Solving and Optimizing; Integrating and Approximating (a Fall, b Spring)

The redesigned replacements for AM 21ab, this pair of classes cover much of the same material as Math 21ab. Historically, these classes can sometimes be much more calculation-based and less theory-based than Math 21a and b, but in the last couple of years the two sets of courses have been more similar. The 22a portion sometimes spends a couple fewer weeks on linear algebra and a couple more weeks on differential equations, which has benefits and disadvantages since both are very important in physics. Logistically, the courses are often taught in one medium professor-led lecture rather than a multitude of small graduate student-led sections, as Math 21a, b typically are. In the end, the Math 21 and AM 22 sequences are pretty similar, and interested students should shop them both to make a decision aligning with their tastes and preferences.

* **Math 22a, b:** Linear Algebra and Vector Calculus (a Fall, b Spring)

This course is primarily for students who are interested in a more theoretical understanding of linear algebra and vector calculus. It covers the same topics as Math 21, but with more rigor and in the opposite order. Math 22 also contains an introduction to mathematical reasoning through proofs. Linear algebra and multivariable calculus are more interconnected throughout this class, as linear algebra techniques from Math 22a are used to prove ideas in Math 22b's vector calculus.

* **Math 25a, b**: Honors Linear Algebra and Real Analysis (a Fall, b Spring)

Math 25 presents a rigorous treatment of linear algebra and real analysis (read: abstract multivariable and calculus). It is intended for math concentrators, but not even a majority of the enrollment ends up concentrating in math. We suggest it for those who would like a deep understanding of elementary calculus from a rigorous, proof-based point of view and who are willing to make a substantial time commitment. While much of the material has no direct bearing on physics, students who qualify for this course can generally learn what is necessary for the physics courses on their own. Realize that this requires a lot of work, and dedication. Thus, for a physics concentrator, this is a "pleasure course" (in the intellectual sense — *not* the workload sense). The official prerequisite is a 5 on the AP Calculus BC exam or permission of the instructor, but there are usually also students who have done math competitions and/or taken the equivalent of Math 21a, b in high school. Make sure you are solid on your math and know enough for your problem sets before taking this class. The pace can vary quite a bit depending on the instructor, so make sure to read past *Q-Guide* evaluations and ask former students.

* **Math 55a, b**: Honors Abstract Algebra and Analysis (a Fall, b Spring)

This course covers the same topics as 25 and 122 but at an even more intense level (and often goes much further in depth). If you are interested in pure abstract mathematics in its own right, the rigors of 55 may be for you, but be warned of the workload. Those who take the course, however, rarely regret it. Like in Math 25, the pace can vary quite a bit depending on the instructor, so make sure to read past *Q-Guide* evaluations and ask former students.

Note that the topics covered in the "a" and "b" semesters do not line up in all the various introductory math sequences. 21 covers multivariable calculus before linear algebra, whereas the other classes roughly cover the same topics in the reverse order. It is easiest to switch between AM22a and 21b, and among 22/25/55, though you can switch easily between any of these classes--consult the math department for more information: https://www.math.harvard.edu/undergraduate/first-year/.

Post-Calculus Courses

Applied Math 104: Complex and Fourier Analysis (Fall)

AM 104 and AM 105 present extremely valuable subjects for physics concentrators, presenting the basis for much of the math used in advanced natural science courses. (Note that the two classes, while often referred to together, are totally independent and may be taken separately.) The material and problem sets in AM 104 are somewhat shorter on theory, which suits some physics majors better than others. Some simple Matlab or Python is incorporated into some of the assignments (an introduction is taught, for any not familiar with it). Some topics covered are contour integration, uniform convergence, and conditional probability. The Fourier analysis component is similar to some of the content covered in Physics 15c, but this class explores the topic in greater depth.

Applied Math 105: Ordinary and Partial Differential Equations (Spring)

This course is a straightforward look into the methods of solving ODEs and PDEs, tools essential to the field of physics. Again, the course is short on theory. The pedagogical progression typically goes as: proof of method, specific example of method, and then general example of method. (Sometimes the proof comes afterward.) If you are able to keep up with the multitude of methods being thrown at you, this course is manageable and most importantly, useful. Some methods will be especially familiar if you have taken Physics 15c. You will find that a multitude of students take this course, from engineers to economists to geologists, though in most years the applications have been physics/engineering-heavy. Some Matlab and Python applications will crop up in this course too.

Applied Math 108: Nonlinear Dynamical Systems (Fall)

The closest you will get at Harvard to an undergrad class in chaos theory (but also check out Math 118r). OK, so this class spends just a few weeks in giving a qualitative explanation of chaos. The other topics it covers are also very relevant to modern physics: oscillations and bifurcations in ordinary differential equations, approximation by maps, and rescalings of systems. The applications to physics are not thoroughly motivated; instead, it focuses on evaluating physical problems through certain techniques. Biology, economics, engineering, and applied math students also take this class, though the systems studied more often come from physics than from any other subject.

Math 101: Sets, Groups and Topology (Fall and Spring)

This course is an introduction to the methods of rigorous mathematics. Through a variety of topics from geometry, analysis, and algebra (the three major subfields of math), students are taught how to write proofs. If you would like to learn how real math is done without the drink-from-the-firehose approach of Math 25+, this course may be exactly what you are looking for.

Many upper-level math courses require the ability to write proofs. Math 22, 23, 25, and 121 are the only other courses that explicitly teach this important skill, and this course cannot be taken for credit if you will also be taking either Math 22, 23, 25, or 55. Since this course teaches brand-new material instead of building on what you've learned already, there are no formal prerequisites. AP Calculus is recommended.

Math 110: Vector Space Methods for Differential Equations

This course looks at finite- and infinite-dimensional inner product spaces, with applications to differential equations, and goes over various forms of the wave equation and Fourier transforms. This stuff is especially relevant for quantum mechanics, and helps you wrap your head around the math in Physics 143a, b. Note that this course is not offered every year, and many people take AM105 in years when this course is not offered.

Math 112: Introductory Real Analysis (Spring)

This course introduces concepts of real analysis (metric-space topology, differential and integral calculus) in a rigorous manner. It treats similar material to Math 23, 25 and 55, though at a less intense pace, and cannot be taken for credit in addition to these courses. Every theoretician (and most physicists in general) should have a working knowledge of real analysis. The class can be variable in how it is taught, however, so check which professor is teaching it and talk to math students.

Math 113: Complex Analysis (Spring)

Complex analysis makes its appearance in all sorts of areas of physics. This course deals with the material in a rigorous manner for its own sake. If your interest in this material is only its use as a calculational tool for physics, you may wish to consider Math 115 or Applied Math 104 in lieu of this course.

Math 114: Analysis II: Measure, Integration and Banach Space (Fall)

An enhanced version of real analysis for people who have completed Math 23, 25, or 55. Topics covered include: Lebesgue measure and integration; general topology; introduction to $L\ p$ spaces, Banach and Hilbert spaces, and duality. Much of the math, especially Hilbert spaces and Fourier analysis, is quite relevant to physical theory, but on the math-y side of things.

*[**Math 115**: Methods of Analysis]*

The course is billed as being designed for those with a strong interest in physics, and indeed most of the subject matter is highly relevant to physics. The course covers the basics of complex analysis and then moves on to applications such as Fourier analysis, Laplace's equations, and Bessel functions, all of which appear frequently in physics. However, most who have taken the course say that few examples relating to physics were presented and thus the relevance was not apparent until the topics appeared in physics courses. We suggest this course for those whose focus lies in physics but who wish to learn the roots of the math more deeply than they might in Applied Math 104.

Math 116: Convexity and Optimization with Applications (Fall)

Just as the title states: an in-depth look at optimization, especially relevant to engineering, applied sciences, and economics. Consult the department for more information.

Math 118r: Dynamical Systems (Fall)

Dynamical systems appear in all sorts of physical processes, and this course provides the mathematical tools necessary to analyze such systems, with an emphasis on applications. It is targeted at both physics and math concentrators.

Math 121: Linear Algebra and Applications (Fall)

This course presents a more complete and rigorous view of linear algebra than Math 21b, which is the prerequisite. It is quite valuable for quantum mechanics. This course is also supposed to be designed to teach proofs should you not already have experience with them. However, it is not to be taken in addition to Math 23, 25, or 55.

Math 122,123: Abstract Algebra (122 Fall, 123 Spring)

The former is an introduction to groups from which most physicists would benefit. (It is quite valuable for particle physics in particular.) The latter focuses on Galois theory and hence is far less relevant for physics. Though these courses do function as a sequence, it is quite reasonable (and common) to take the former without the latter.

Math 131: Topology I: Topological Spaces and Fundamental Group (Fall)

An introductory course in topology. Very interesting, but only relevant for gung-ho theorists. If that's you, though, this stuff is essential. Familiarity with groups (via Math 101 or 122) would be helpful, though some people pick it up as they go along.

Math 132: Topology II: Differential Topology (Spring)

An independent course from Math 131, aimed at students with Math 23, Math 25 or Math 55 background. Topics covered are: differential manifolds, smooth maps and transversality, winding numbers, vector fields, index and degree, differential forms, Stokes' theorem, and an introduction to cohomology. The math is relevant to what's behind general relativity and other deeper theories, though in a fairly abstract, indirect sense.

Math 136: Differential Geometry (Fall)

The course is an introduction to Riemannian geometry with the focus (for the most part) being the Riemannian geometry of curves and surfaces in space where the fundamental notions can be visualized. The topics in this course are closely related to general relativity and might be appealing to Physics-Math concentrators looking for a 130-level course.

Applied Math 201: Physical Mathematics I (Spring)

This course offers an introduction to methods for developing accurate approximate solutions for problems in the sciences and integration with numerical methods and solutions. Topics include: dimensional analysis, algebraic equations, complex analysis, perturbation theory, matched asymptotic expansions, approximate solution of integrals.

*[**Applied Math 203:** Introduction to Disordered Systems and Stochastic Processes]*

While this is a class that is purportedly about applied mathematics and statistics, when taught by Prof. Ariel Amir, it largely serves as a thrilling survey of various topics in equilibrium and non-equilibrium statistical mechanics and disordered systems. Even topics that are not exactly physics (e.g. random matrix theory) are either strongly related to it or rely on intuition from statistical physics. At the end of the day come for Black-Scholes (and fat stacks), leave with percolation, barrier crossings, and the Langevin equation.

Astronomy Department Courses

* **Astronomy 16**: Stellar and Planetary Astronomy (Spring)

Astronomy 16 is a class aimed at incoming freshmen with an interest in astronomy. The only corequisite is 15a, although Astro 16 is offered in the spring. This class is a fun introduction to the field of astrophysics, and is highly recommended for those considering further pursuit of astronomy as well as those who are interested in the subject. Astro 16 deals with topics like stars, the Solar System, exoplanets, and orbital dynamics. However, the structure and the workload of the class can be highly dependent on the professor teaching it, so consult the Q guide reviews to determine if this class will be right for you.

The course also has an observational component: in one lab, you will determine the distance to the Sun, and in the other lab, you will use the Clay Telescope atop the Science Center to study an eclipsing binary star. A highlight of the class is the optional exoplanet lab where students use the Clay Telescope to observe the transit of a known exoplanet. If you are successful, you will get an automatic A for the class.

* **Astronomy 17**: Galactic and Extragalactic Astronomy (Fall)

This course, offered in the fall, deals with the physical principles of galaxies, cosmology, the Cosmic Microwave Background, and, more generally, the universe. It forms a set with Astronomy 16, although 17 is a relatively newer course. This course recently added an observation analysis component, where you look at images from astronomical surveys or analyze spectra of galaxies, which is a great sneak peek at current research in the field. Note that you can take 16 and 17 in any order if you want, but 16 before 17 makes the most sense. Just like with microeconomics and macroeconomics, it seems as though getting the smaller scale picture before the bigger scale picture is most effective. Similar to Astronomy 16, this course only requires concurrent enrollment in mechanics.

Astronomy 91r: Supervised Reading and Research (Fall and Spring)

This is just like Physics 90r and 91r combined, but with an astronomy focus.

Astronomy 98: Research Tutorial in Astrophysics (Fall and Spring)

This introductory tutorial is normally open to juniors considering a concentration in astronomy or a joint concentration. This is an excellent way to get a broad overview of a topic and see what is actually being done at the forefront of research. We highly recommend this course for anyone even vaguely considering an astronomy concentration or focus. Astronomy 16 or 17 is the official prerequisite.

Astronomy 100: Methods of Observational Astronomy (Spring)

This course teaches you how to use the basic tools of astronomy research: telescopes, spectrometers, detectors, etc. The course is designed to give you a realistic, hands-on approach to examining astronomical data, and students report that it is successful in that regard as well as an enjoyable class. The class also takes a trip over spring break (make sure you have that time free!) to the F. L. Whipple Observatory on Mount Hopkins in Arizona, which is always fun. Note that although work during the semester is not overly rigorous, the final project typically requires a substantial time investment.

Astronomy 110: Exoplanets (Fall)

Consult the department for more information.

*[**Astronomy 120**: Stellar Physics]*

Consult the department for more information.

Astronomy 130: Cosmology (Fall)

Consult the department for more information.

Offered every other year, alternating with Astronomy 140.

*[**Astronomy 140**: Introduction to General Relativity]*

Consult the department for more information.

Offered every other year, alternating with Astronomy 130.

Astronomy 191: Astrophysics Laboratory (Spring)

The astrophysics lab course is intended for concentrators in astronomy or dual concentrators; however, physics concentrators with a demonstrated interest in astronomy may take it. As always, if you're not sure if you're eligible, check with Prof. Paban or Dr. Klales. Unlike Physics 191r, Astronomy 191 presents more opportunities for participation in real research, and past projects have actually produced publishable results. This course is highly recommended for students with an interest in astronomy who want a taste of real research.

Astronomy 200: Radiative Processes in Astrophysics (Fall)

This class, primarily for graduate students, investigates light in all of its astrophysical detail, covering various emission mechanisms and radiative transfer. While students with no astronomy experience but a strong physics background could survive this course, background is recommended.

Astronomy 201: Astrophysical Fluids and Plasmas (Spring, every 2 years)

A great fluid dynamics class offered in the astronomy department. Knowledge of mechanics, thermodynamics, and E+M along with comfort with vector calculus is strongly recommended. Fluid dynamics is not offered in the physics department, but it's an important subject to know nevertheless! A fair amount of work is needed, but when taught by Prof. Lars Hernquist, it is an especially great, low-stress class.

Other Cool Stuff

* **Computer Science 50, 51**: Introduction to Computer Science; Abstraction and Design in Computation (50 Fall, 51 Spring)

These courses present an introduction to computer science and programming, including languages such as C, PHP, SQL, ML, and Java. CS50 is one of the most popular classes at Harvard, with an enrollment of more than 700 students last year. The programming skills and computer knowledge presented in CS50 will be valuable both in general and to someone considering a career in science. The material covered in CS50 is highly recommended, though there may be less painful ways to pick up that knowledge. CS51 tends to be less immediately relevant to physicists.

Statistics 110: Introduction to Probability (Fall)

This course gives a thorough overview of probability theory, including common probability distributions and conditional probability (unlike the sub-110 Stat classes, which brush over probability theory and focus on applications in data analysis). Comfort with basic probability theory is very helpful in quantum mechanics and statistical mechanics, and while Stat 110 is certainly not required, it provides a solid foundation in probability for physics and then some. It can also be a very enjoyable class: it involves a different kind of intuition from typical math, and it's been wonderfully taught by Prof. Blitzstein in the last few years with enrollment continuing to grow.

Engineering Sciences 181: Thermodynamics (Fall)

This is a thermodynamics and statistical mechanics course similar to Physics 181, but with a focus on more practical applications, and emphasizing thermo over stat mech. Most people find it more comprehensible as well. We highly recommend either Physics 181 or ES 181, with physics being the choice for those who will study thermo and stat mech more deeply later (most physics concentrators), and probably ES for those who just need to have some thermo in their lives (all physics concentrators, in our opinion).

Many other Engineering Sciences courses are also relevant to physics. Check out *Courses of Instruction*, and talk to engineering concentrators for more information (especially about instructors). Below we have listed some particularly related to physics (whose topics are not as well covered in physics courses):

Engineering Sciences 120: Introduction to the Mechanics of Solids

(Spring)

Engineering Sciences 123: Introduction to Fluid Mechanics and Transport Processes (Spring)

[***Engineering Sciences 135****: Physics and Chemistry: In the Context of Energy and Climate at the Global and Molecular Level*]

Engineering Sciences 154: Electronic Devices and Circuits

*[**Engineering Sciences 170**: Engineering Quantum Mechanics (Spring)]*

*[**Engineering Sciences 173**: Introduction to Electronic and Photonic Devices (Fall)]*

Engineering Sciences 190: Introduction to Materials Science and Engineering (Fall)

[***Dramatic Arts 163x****: Puppetry in Performance*]

Puppet theater has almost nothing to do with science, with the possible exception of the annual puppet show put on by second-year grad students, and we mention it here only to see if you are still reading :)

* **Life and Physical Sciences A / Life Sciences 1a**; Physical Sciences 1 (Fall)

These courses represent a standard year-long introductory course in chemistry. We recommend a basic knowledge of chemistry for all physics concentrators simply because we think broad backgrounds are important for avoiding falling into thought ruts later in life. Also, you may learn important skills for making exciting demonstrations involving fire.

Unfortunately, these classes are ***very*** large and tend to be dominated by pre-med and biology students, which can be frustrating.

* **Chem 10**: Quantum, Statistical and Computational Foundations of Chemistry (Fall)

* **Physical Sciences 11**: Foundations and Frontiers of Modern Chemistry: A Molecular and Global Perspective (Spring)

These courses, besides your typical introductory general chemistry material, intend to introduce fields and applications that you might not get to outside of more advanced physics and chemistry classes. Chem 10, for instance, goes over the fundamentals of quantum mechanics and statistical mechanics, while PS 11 looks at topics such as thermodynamics and quantum chemistry, both with many real-world applications. Consult with the department for more information.

* **Chemistry 20, 30**: Organic Chemistry (20 Spring, 30 Fall)

This sequence is Harvard's organic chemistry sequence for chemists and other science concentrators that want a taste of real chemistry (although a few humanities and social science concentrators make an appearance). Most Chem/Phys concentrators take this route over the alternative (Chemistry 17/27).

These courses have a reputation of being both difficult and time consuming, so keep that in mind when planning your schedule. They are, however, well-taught and organized and are very fulfilling for those who are interested.

Chemistry 40: Inorganic Chemistry (Spring)

This course is both useful for Chem/Phys concentrators as well as anyone with an interest in materials science. Consult the department and other students for more information.

Chemistry 160: Quantum Chemistry (Fall)

This course is an introduction to quantum for chemistry people. If you are interested in a chemist's perspective on quantum mechanics, this may be the course for you. However, Physics 143a is required of all pure physics concentrators, and thus this course has relevance primarily to Chem/Phys concentrators. Chemistry 160 focuses more on measurable results of quantum theory, while Physics 143a focuses on the mathematical underpinnings of quantum mechanics. This course is also known for emphasizing computational tools over analytical calculations.

Chemistry 161: Statistical Thermodynamics (Spring)

This course is unlike Physics 181 and ES 181 in its strong focus on chemistry. Though not recommended for those interested in the physical aspects of thermodynamics, it is certainly a good choice for Chemistry concentrators with an interest in physics or for Chem/Phys concentrators. It also serves a good introduction to some topics in biophysics research.

Once again, there are lots of other good chemistry courses of interest to physics concentrators.

Neuroscience 131: Computational Neuroscience (Spring)

Neuro 131 is a fascinating course on modern brain theory taught by a former theoretical physicist (Haim Sompolinsky) turned theoretical neuroscientist. It builds up mathematical models of neural computation using inspiration from statistical mechanics, information theory, and statistical inference, among many other subjects. Do not be fooled by the course number; Neuro 131 is a graduate-level class and is mathematically very rigorous, but ultimately is worth it if you are interested in exploring how quantitative techniques from physics and other related domains can be used to try and explain how the brain works.

Other departments that have more specialized courses of interest to physics concentrators include Earth and Planetary Sciences, and Molecular and Cellular Biology, so check with their concentrators or the Courses of Instruction for more details. The History of Science and Philosophy departments also offer interesting courses relating to physics that are good fun even though they don't count for concentration. They're also really wonderful for people who have no inclination to concentrate in physics. For those who just wish to dabble in physics, many of the Science and Technology in Society (Gen Ed) courses are excellent (and people tend to forget... there's no maximum to the number of Gen Eds you can take). There are about 1800 other courses in the catalog that might interest you as well, so take a look!

MIT Courses

MIT offers some physics courses (Course 8) that may not be offered here. Most notable is an undergrad class in string theory (8.251)! For more information, go to http://catalog.mit.edu. Here are a few that some physics concentrators have enjoyed over the years.

8.333-4: Statistical Mechanics of Particles/Statistical Physics of Fields (8.333 Fall, 8.334 Spring)

Statistical physics is an extremely deep and beautiful subject with various motifs that are undercurrents in modern research, especially in condensed matter. An alternative to Physics 262 is cross registering for 8.333 & 8.334 at MIT. While 262 in principle covers much of the material in 8.333 & 8.334 and is brilliantly taught, Prof. Kardar's 8.333/4 course is an invaluable experience which covers similar material in a clear, highly rigorous, and deeply technical manner.

8.613 / 22.611: Introduction to Plasma Physics I (Fall)

A hidden gem of the MIT physics department, this is the first of a series of graduate courses in plasma physics. Although plasma physics is a relatively small subfield, it is essential to astrophysics, controlled fusion, and many other fields. This course is a must-take for anyone interested in the subject and a great addition to your schedule after Physics 153.

Some Notes on Feedback

The SPS does a lot of work to make sure the advising system and classes offered at Harvard for physics students are truly worthwhile. It's why we meet with members of the department so frequently and also why we make this booklet – so students can make informed decisions.

In order to help us along, we need you to participate in this process of continual reform. Come to SPS meetings and let us know what needs to be fixed! Fill out *Q-Guide* evaluations! And don't just wait until someone tells you about giving feedback – the Derek Bok Center for Teaching and Learning has an anonymous feedback form (bokcenter.harvard.edu) that provides anyone (a professor, TF, advisor, anyone with an email address) with immediate comments. Your feedback is key to informing future students about classes and also directly improving the department's curriculum.

Research at Harvard

Do it. Do it! **Do it!** Undergraduate research is one of the most valuable experiences Harvard has to offer.

Don't think that research is only for those who already know what area of study they would like to pursue. One of the best ways of seeing if you like something is doing it! Therefore, research may actually be *more* important for those who are undecided.

Fortunately, Harvard's science departments have plenty of opportunities for undergraduates. There are quite a few reasons why you would want to do research. For one thing, research can often be a very exhilarating and rewarding experience. It will give you a glimpse into the life of a scientist and the nature of real science beyond the sterile classroom environment. It also looks really good on graduate school applications — even if you don't apply to the field in which the research was performed – and is practically required for graduate school in experimental physics.

Unfortunately for the undergraduate, most professors would like you to have some clue about something before you begin. So, let's begin with that.

Good things to know

Computers are indispensable tools in pretty much every branch of science these days. Theoretical physicists use them to simulate mathematical models, experimentalists perform complex data analysis and reduction, chemists do molecular modeling, and computer scientists make them do all sorts of neat things. A background in programming is highly sought after (though by no means necessary!) in research positions. Many scientists these days are amateur programmers by necessity; you can become one too with a little effort. If you happen to be a *real* programmer, though, so much the better -- you can be very valuable to a faculty member. What (usually) matters is not so much which languages you know as a general ability to make the computer do what is needed of it. If you'd like to get your feet wet, check out CS 50 and 51, as well as courses in other departments (such as AM 111) -- or pick up a book and learn some yourself.

Mathematica, Matlab, and Python are becoming increasingly important in both theoretical and experimental physics. Many of the introductory math and physics courses use them, so they often provide a short tutorial. There is also a course offered by Earth and Planetary Sciences called EPS 100: The Missing Matlab Course, which provides a more formal introduction to Matlab, although it seems that the labs are geared toward the earth sciences rather than math or physics. The ability to use programs like Mathematica and Matlab effectively will win you friends very, very quickly. Once you've got the hang of one of them, though, put it on your resume! Professors will love you if you can teach them how to get more out of the tools they're already using.

On the other end of the spectrum, experience with electronics can also be a plus. Even a basic understanding of how to put together simple circuits can be useful in getting in the door to a more hands-on research experience. (Physics 113 might not be a bad way to get started.) Some labs may have you building things in the machine shop, located in the basement of Lyman. It is also open for general use for physics and SEAS students. Be sure to check out the training classes offered there if you'd like to start.

But in general, most professors don't really expect much previous laboratory experience from their undergraduate students, since most labs are very different and experience in one often does not completely prepare you for another. Basic concepts such as lab safety and care of expensive equipment are generally all they ask. The professors and graduate students will help you learn everything you don't know ahead of time (which will be a hefty majority of what you'll be doing no matter what experience you bring to the job).

Many professors would like some course experience, though this is highly dependent on the type of work. In general, the introductory courses in each department are a good launching point. But far more important is your attitude and the interest you display in their particular area of research. Even if you don't really know anything about their field, they'll be interested if you seem to be genuinely curious about it.

How you can get involved

"So how do I get hooked up with a job?" you ask. Well, it's all up to you. Truth be told, the physics department won't go out of its way to just hand you a job. You have to take the initiative yourself. But you, being a resourceful and intelligent Harvard undergraduate, should be undaunted. Professors *want* to hire you; you just need to make sure they know you exist. Here are a few tips:

*** Talk to professors**

This is all there is to it. If you might like to work for someone that teaches one of your classes, go to office hours and ask them about their work and their colleagues' work. The physics department website also lists professors by research area. If the research sounds interesting, ask the professor if they need some help! Professors may not even know they need an assistant until you tell them so. And don't be afraid to knock on the door of random professors. (In this modern age, we recommend an email to introduce yourself and schedule an appointment ahead of time.) To give guidance to this random knocking, most departments publish lists of the research taking place for their graduate students. There is, however, no reason an undergraduate shouldn't get a copy of that list and look it over. Once again, the initiative is yours. If something sounds interesting, get in touch with the professor.

* Talk to students who already have jobs

You might also hang around in the department you'd like to work in: talk to the students who are already working there! Most of the happy students didn't find their position through official channels. They might know who needs help, or who else to talk to. Again, you are welcome to contact the SPS officers, or any other members of the SPS, to ask for advice.

* Check department offices and the SEO

If a particular professor is in need of students, they may make that known to the department office. Department offices are a good first contact point. Another source is the Student Employment Office. Some professors in desperate need of students will post on the SEO's bulletin boards. Check those out. The SEO is online at www.seo.harvard.edu.

* Attend departmental seminars

Another way of finding out about interesting research is to attend the seminars held by most departments. The Physics Department, for example, holds a Wednesday night lecture series (in conjunction with Physics 95) in which professors speak about their research at an undergrad level. Also look out for the Monday Physics colloquia. It is important not to be intimidated by research you cannot completely understand. In fact, "I was really interested but I didn't quite follow this part . . ." can be a good way of opening conversation with the professor later. If you get involved, you'll learn quickly enough.

* Attend *Chilloquium*

In the Summer of 2020, Harvard SPS inaugurated a brand-new program that has continued to flourish: we started *Chilloquium*, a more relaxed version of your typical colloquium that's tailored for undergraduates like you. We encourage you to attend these talks! They're a really good way to get a quick survey of different fields of research that you might not have experience with, and also to hear about different researchers who are engaged in extremely cool physics but who might not have the biggest exposure yet. We've hosted over 40 speakers, both during the school year and the summer.

*** Ask your Polaris mentor**

In 2020 we started the first-ever Polaris program at Harvard SPS. This new mentoring program paired underclassmen with upperclassmen and graduate students in order to help guide them through their physics career at Harvard. Polaris mentors and mentees would all meet together periodically over the school year, and mentees could have people who had already been through the ringer to ask their innumerable questions to without being intimidated by the shiny title of a professor staring them in the face. This year, we plan on holding in-person events, so stay tuned for those and sign up for Polaris, whether you're an underclassman looking for some guidance, an upperclassman with a kind heart looking to give back to the physics community, or you just want some free food!

*** Attend other physics events**

While we're on the topic of seminars, it's good to know that there are enough talks in the area to replace your course load. At Harvard, there are not only departmental talks (physics, chemistry, astronomy, etc.), but also subgroup seminars (Materials Science, Squishy Physics, Condensed Matter, High Energy Theory, CNS, various CfA divisions). Outside of Harvard, there are even more opportunities: sign up for the weekly Boston Area Physics Calendar (BAPC) email list at cosmos.phy.tufts.edu/bapc.html. Also, the SPS hosts regular *Chilloquia* throughout the year (and summer), and we often have Harvard professors give talks. This is a great opportunity to get to know the professor, learn about their research in a relaxed fashion, and see if you like it!

*** Check out tutorial courses**

Yet another way to find out about research is through the tutorial courses offered by most departments. These provide a more in-depth discussion of various professors' research as well as personal interaction with the professors. We highly recommend the introductory tutorial in the department of Astronomy.

*** Check the Radcliffe Institute**

The Radcliffe Institute for Advanced Study has a number of fellows every year that are looking for enthusiastic undergraduates to help them with their research. Contact the Institute or professors individually; also talk to students for their experiences. Many of the applications are usually posted on the SEO database as well.

*** Talk to department offices and Head Tutors**

For all these departments—Physics, as well as Chemistry, Astronomy, and the School of Engineering and Applied Sciences (which includes Applied Physics, Computer Science, Engineering Sciences, Applied Mathematics, and Earth and Planetary Sciences)—start by contacting the department office and the head tutor. If you are Astronomy inclined, the Director of Undergraduate Studies (Professor Öberg) usually sends out a compiled list of faculty members and researchers at the Center for Astrophysics who are specifically looking for undergraduates.

To be honest, as a first year, you probably won't get involved in heavy-duty research. But you'll probably have your hands full with classes and socializing anyway. If you have special skills you can probably make yourself useful, and you can at least start cultivating contacts that will help you find summer and term-time jobs in the future.

Summer Jobs and Research

For summer jobs, in addition to local employment, there are many opportunities outside of Harvard. For example, check out the Rowland Institute for Science (www.rowland.org) and other universities and companies in the area. The department office compiles a notebook with summer opportunities for undergraduates. Additionally, the SPS will disseminate information over email. There are also many summer programs with sites on the web.

"REU"s (Research Experiences for Undergraduates) are one of the most popular ways to get paid to do research over the summer. The NSF runs a network of REU programs in all branches of science and engineering. The central homepage is at www.nsf.gov/home/crssprgm/reu. Deadlines for these programs are often pretty early — January and February are common.

There are also many Harvard programs that will fund research at Harvard, in the US, and abroad: for example, PRISE, HCRP, Herchel Smith, and Weissman. Check them out at the URAF (Undergraduate Research and Fellowships) website here: uraf.harvard.edu/undergraduate-research. The Physics Department also provides funding, supplemental to HCRP funding, to support students doing research on-campus with a physics professor.

Be forewarned that there is a lot of competition for these positions (especially REUs) and freshmen are unlikely to snag them. But they often do take note of the brave people who apply against all odds, and first year applicants are sometimes solicited the next year. Also note that most of these have a more formal application including letters of recommendation from professors. So go to those office hours and buddy up to your professors! Knowing and being liked by a few professors has benefits far beyond summer job applications. Just let some of their fame and glory ooze onto you.

For students looking to go abroad, RISE (Research Internships in Science and Engineering) is a neat summer internship program at institutions all over Germany for students from the US, Canada, and the UK. A number of Harvard students have done it, so talk to them for more information. The website is www.daad.de/rise/en.

The Physics Department website has a good list of places to do research: www.physics.harvard.edu/undergrad/summer

When to start scoping out the profs

As early as possible! For summer positions, deadlines can start approaching as early as November and continue into the spring. You should start talking with professors in December or early in the Spring semester, ideally before February for many grant deadlines. Term-time employment is often more flexible and professors may be hiring at any time. Still, if possible, making contact during the summer can be a good idea. Also, keep at it! If you walk into any professor's office you are likely to see a desk piled so high with papers you can't even see the little sign saying "A disorganized desk is a sign of genius." That note with your phone number can easily get lost in that vastness. Pester professors until they hire you or send you to another professor to get a job. They can be pestered in person, by phone, or via email (physics professors are generally available via email at lastname@physics.harvard.edu). And if you've submitted something to a department office, definitely pester them. Bureaucracy *can* move if it is prodded enough.

What I really want to know about: $$$$$

The first thing to decide in undertaking research is whether you want to get paid! There are a lot of grants out there that can help you out, even if your professor is feeling a little strapped for cash. For the grants discussed below, deadlines are usually early and pretty stringent. Semester applications are due either before the semester begins or very early on (1 or 2 weeks afterward) and summer applications can be due as early as February.

If the research experience is more important to you than money, you have more options. The 90r series of courses in Physics, Astronomy, Chemistry, and Engineering are an easy way to do research. You won't get paid, but at least you'll get credit! Another advantage is that you're almost guaranteed not to be doing grunt work. If you are, talk to someone. There is better research to be done.

If you're feeling very generous, you may wish to work for some professors for a while without pay until you've learned the ropes. This is a good way to negotiate a position somewhere you really want to work even though the professor wants experience you don't have. It also gives the professor time to free up or find funds to pay you with.

Okay, you say, cut the altruism. I want dough. Well, don't expect to become rich overnight (or ever, for that matter). Most research positions will keep you somewhat lean. There are some ways to increase those paychecks, however. If you qualify for the Work-Study program, professors will love you because it pays a big chunk of the bill (though be careful with the logistics behind it). If not, make sure your professor applies for a Faculty Aide grant. This fund will provide half of your pay up to a certain amount.

Another important thing to know about is the Harvard College Research Program. Grants from this program will pay you to perform almost any kind of research under the guidance of a faculty adviser. The grants last one semester, so there are three deadlines throughout the year (for fall, spring, and summer). More information is available on the HCRP website at uraf.harvard.edu/research-funding.

There are plenty of other sources of funding – search around and you're guaranteed to find something. If you work at the CfA, and your professor works for NASA or NSF, they can apply for additional funding from them, just for you. A relatively new grant is the APS/IBM Women in Science Internship, which is especially for women in the "hard sciences." Other grants are available; the Student Employment Office and department offices can help you find them. In addition, try out the Office of Career Services. They publish a book called "The Harvard College Guide to Grants" which you can look at for a few minutes by sacrificing your Harvard ID briefly or by purchasing for $5.

For summer research here on campus, the Physics Department (in tandem with HCRP) essentially guarantees funding. See Dr. Klales for details on how to apply.

Good luck, and remember to invite us to Stockholm when you get your Nobel Prize!

Contacts

Below we have tried to list some important people and web pages. You can always find phone numbers from Harvard Information, 5-1000. And we hear this World Wide Web thing is pretty useful for finding information, too.

Department of Physics, Lyman Laboratory, 2nd floor

www.physics.harvard.edu

Chair, Cumrun Vafa (vafa@physics)
Director of Administration, Despina Bokios (despina_bokios@fas)
Director of Undergraduate Studies, Sonia Paban (sppaban@fas)
Associate Director of Undergraduate Studies, Anna Klales (aklales@g)
Physics Concentration Advisor, David Morin (djmorin@fas
Undergraduate Program Administrator, Dionne Clarke (dlclarke@fas)

The email address of Professor *Lastname* of the Physics Department is usually: lastname@physics.harvard.edu or lastname@fas.harvard.edu.

Society of Physics Students

If you have questions about anything related to physics at Harvard, please don't hesitate to reach out to any of the following contacts!

Our Co-Presidents:

Annika Geiersbach '27 (acgeiersbach@college.harvard.edu)

Mary Cipperman '26 (mcipperman@college.harvard.edu)

Our general address:

harvardradcliffesps@gmail.com
(if you don't get a response within a week, email one of the officers on one of the committees to which your concern pertains.)

For events, pictures, and more, go to

https://sps.physics.harvard.edu/

Sign up for our mailing list:

sps-list@lists.fas (major SPS and Department announcements): https://web.lists.fas.harvard.edu/mailman/lists/sps-list.lists.fas.harvard.edu/

This year, we've made many more committees with many more people on these committees, so that we can do much more stuff this year. These committees are as follows: Polaris, Equity & Inclusion, Events & Panels, Chilloquium, Directed Reading, Undergraduate Seminar, and Communications.

Postal mail, although we haven't the foggiest idea of what you'd ever want to mail us:

H/R Society of Physics Students
Jefferson Laboratory
Harvard University
Cambridge, MA 02138

Other Departments and Important People

Department of Astronomy, Observatory P-212
astronomy.fas.harvard.edu

Center for Astrophysics
www.cfa.harvard.edu

Charles Alcock , Director of Undergraduate Studies in Astrophysics
calcock@cfa.harvard.edu

Department of Chemistry, Mallinckrodt 118
chem.harvard.edu

Gregg Tucci, Head Tutor in Chemistry
tucci@fas.harvard.edu

Department of Earth and Planetary Sciences, Hoffman 4th fl.
www.eps.harvard.edu

School of Engineering and Applied Sciences, Pierce 212a
www.seas.harvard.edu

Department of Mathematics, Science Center 325
math.harvard.edu

STAHR (Student Astronomers at Harvard-Radcliffe)
www.hcs.harvard.edu/~stahr

Harvard Chemistry Club
www.hcs.harvard.edu/chemclub

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The preceding wonderful and useful booklet was prepared by the Harvard-Radcliffe Society of Physics Students, a non-profit organization (a *really* non-profit organization) dedicated to making physics students happy through mentorship and advising, establishing excitement about the wonderful field of physics, and by fostering a social and friendly physics community. And, of course, obtaining free food. All are welcome to join our meetings.

This booklet was originally written by Derrick Bass, Theresa Lynn, and Cynthia Phillips. It was updated in 1996 and 1997 by Charlene Ahn and Ben Rahn; in 1998 and 2000 by the then SPS Officers; in 2001 and 2002 by Craig Hetherington and Genevieve Reynolds; in 2003 by William Zaientz; in 2004 by Doug McClure, Bart Horn and Marc Parris; in 2005 by Peter Williams; in 2006 by Limor Spector and Bailes Brown; in 2007 by Benedict Huang and Ognjen Ilic; in 2008 by Lin Cong; in 2009 by Kenny Gotlieb and Anjali Bhatt; in 2010 by Nikko Pomata; in 2011 by Phil Yao, Marlee Chong, Kristin Barclay, Amy Chen, Tom Rice, and Annie Baldwin; in 2012 by Joanna Behrman and Amy Chen; in 2013 by Kate Donahue, Amy Chen, and Abel Corver; in 2014 by Mark Arildsen and Eric Metodiev; in 2015 by Mark Arildsen, Patrick Komiske, Eric Metodiev, and Eric Anschuetz; in 2016 by Eric Anschuetz, Kaan Yay, Sidharth Chand, Alexander Nie, and Samuel Liu; in 2017 by Kaan Yay, Peter Chang, Adam Frim, Samuel Liu and Pradeep Niroula; in 2018 by Elba Alonso-Monsalve and Vaibhav Mohanty; in 2019 by Maya Burhanpurkar, Abijith Krishnan, Sambuddha Chattopadhyay, and Dan Stefan Eniceicu; in 2020 by Benji Kan, Sambuddha Chattopadhyay, and Rajath Salegame; in 2021 by Andrew Winnicki and Benji Kan; in 2022 by Qijia Zhou, Josh Josephy-Zack, and Emma Weller; in 2023 by Elizabeth Kozlov and Jorge García Ponce; in 2024 by Savanna Coffel and Iris Sung; in 2025 by Mary Cipperman and Annika Geiersbach. We take sole responsibility for the opinions expressed in this book and once again caution you that much of this material is opinion.

We would also like to thank the following people for their valuable help and insight:

Derrick Bass, Carol Davis, Gary Feldman, Howard Georgi, Margaret Law, David Morin, and Chris Stubbs

We would greatly appreciate feedback on this booklet: did it help you? Which sections were most useful? Would you like to see more of something, less of something? Suggestions for other sections, better organization, a better title, or a more fashionable wardrobe for SPS officers are welcome. Drop comments in the SPS box, give us a call, or send us an email!

Have a wonderful year, and we hope to see your picture on the concentrators' bulletin board in the spring!