Beyond Math 1: Which math course is for you? (2018-2019)

If you have completed the Math 1a/1b sequence at Harvard or if you have had the equivalent material elsewhere, you may be wondering which course is for you. The mathematics department provides a variety of options which you should consider based on your academic interests and your background. With exceedingly rare exceptions, students in your position are advised to take one of Math 18, 19a, 19b, 21a, 21b, 22a, 23a, 25a, 55a. You can also take Math 101 concurrently with any of Math 18-22. (The School of Engineering and Applied Sciences also offers Applied Math 21a,b which covers much the same topics from Math 21a,b.) This pamphlet describes the Mathematics Department's offerings and should help you decide which course is for you.

- Math 18: This course is taught in the fall only. Math 18 covers the concepts and techniques of multivariable calculus most useful to those studying the social sciences, particularly economics. The course also serves as an introduction to mathematical modeling in the social sciences and economics. Math 18 should not be taken in addition to Math 21a, but Math 19b or Math 21b may be taken before or after Math 18.

- Math 19a: Math 19a is given in just the fall; it teaches multivariable calculus and differential equations for applications to the life sciences. It is recommended by those taking the new Life Science 1a,b courses and by the life science concentrations (this means Biological Anthropology, Chemical and Physical Biology, Human Evolutionary Biology, Molecular and Cellular Biology, Neurobiology, Organismic and Evolutionary Biology, and Social and Cognitive Neuroscience.) In particular, the focus in Math 19a is on differential equations, both linear and non-linear in one or more variables. Related techniques are also presented. Math 19a has a second focus which is mathematical modeling for life science problems. This course is preferrable to Math 21a for those majoring in a life science except for students who plan to take Physics 15/16.

- Math 19b: This course is given only in the spring semester. Math 19b is also for life science concentration people and those taking Life Science 1a,b. The course teaches linear algebra with enough probability and statistics to forgo the beginning statistics courses such as Stat 100, 102, 104. Math 19b is spring only. This course teaches all of the linear algebra in Math 21b, but it trades

the differential equations part of Math 21b (which is taught in Math 19a) for the probability and statistics.

⋆ NOTE: Math 21b can be taken after Math 19a and Math 19b can be taken after Math 21a. (But Math 19a and Math 21a can not both be taken, nor can Math 19b and Math 21b.)

- Math 21a: This course covers the basics of multivariable calculus in two and three dimensions: Curves and surfaces, functions and their derivatives, the calculus of variations, multi-variable integration, integration on curves and surfaces, multivariable generalizations of the fundamental theorem of calculus. In short: Math 21a teach the tools and intuition for dealing with basic multivariable problems. Math 21a is given in both the fall and spring semester.

- Math 21b: This course covers the basics of linear algebra in dimensions 2, 3 and higher. A significant part of the course uses the linear algebra to study ordinary and partial differential equations. Math 21a and Math 21b can (in principle) be taken in either order, but most students take Math 21a first. (Also, the abstract parts of Math 21b are probably easier to follow having taken Math 21a.)

- Math 22a,b: This course covers multivariable calculus and linear algebra for students interested in theoretical sciences. It covers the same topics as Math 21a,b but with more rigor. Students are taught techniques of proof and mathematical reasoning. The workload and content is comparable with the 21 sequence. But unlike in the later, the linear algebra and calculus is more interlinked. Math 22b can be taken after Math 21a and Math 21b can be taken after Math 22a.

- Math 23a,b,c: This sequence likewise treats multivariable calculus and linear algebra in a rigorous, proof-oriented way. It differs from Math 21a,b and Math 22a,b by virtue of it being taught in a format where students watch videos before class and then do presentations and problem solving in class. Math 23a,b,c also makes extensive use of computational tools (R-script). Various applications for other science and social science concentrations are presented also. Math 23a is the fall course. Students can take either Math 23b or Math 23c in the spring (Math 23c is geared somewhat towards data science applications.) Note that this course is typically more time consuming than Math 21a,b (but for the most part, not as time consuming as Math 25a,b).

- Math 25 and 55: These are theory courses that should be elected only by those students who have a particular interest in and enjoyment of abstract mathematics, as well as a solid understanding of one-variable calculus. (But note that many of the students in these courses go on to concentrate in other sciences.) These courses assume a willingness to think rigorously and abstractly about mathematics; and they require a willingness to work hard. Both courses study multivariable calculus and linear algebra plus many very deep, related topics. These courses come with an iron clad guarantee that you will be challenged by the mathematics.

✶ CHOOSING BETWEEN MATH 22, 23, 25 OR 55: Math 25 differs from Math 22 and Mathematics 23 by virtue of the work load in Mathematics 25 being significantly more than in than in these other courses; but then Mathematics 25 covers more material. Even so, any given course that asks for Math 25 as a prerequisite accepts Math 23 and Math 22 as well. As noted above, Math 23 differs from Math 22 in that material in Math 23 is learned from video lectures whereas classroom time is dedicated to presentations and problem solving. Meanwhile, Mathematics 55 differs from Mathematics 25 in that the former assumes an extremely strong proof oriented mathematics experience. Entrance into Mathematics 55 requires the consent of the instructor.

✶ SKIPPING MATH 25/55: Every year a few first year people with advanced backgrounds want to skip Math 25 and Math 55 and start with a 100- or 200- level course. Based on many years of experience, we *discourage* this. You may learn more advanced material in higher level courses, but never at the same speed and intensity as in Math 25 or 55. Moreover, you are learning more than just a body of mathematics in these courses. You are also learning how to 'be' a research mathematician (as opposed to one who only does well in math courses). If, in spite of this warning, you think that taking a higher level course as a freshman would best serve your needs, you should speak to the Director of Undergraduate Studies in Mathematics.

- Applied Math 21: The Applied Math 21a,b sequence is much like Math 21a,b with regards to content, but it is taught from a somewhat more applied point of view. These courses are taught in a single large lecture hall format, whereas Math 21a.b are taught in small sections that are designed to maximize student/ teacher interactions. (Mathematics concentrators can use Applied Math 21a,b as as related field courses for concentration credit if they do not also take Math 21a,b.)

OTHER COURSES:

- Math 101: Math 101 (fall semesters) is designed to give people with a Math 1b level background and with interest in mathematics a taste of what modern mathematics is all about. This course can be taken concurrently with Math 21a or 21b or 22a. It is not to be taken with Math 23, 25 or 55 (without special permission). Math 101 also gives a good background for writing and following mathematical proofs. This skill will be needed in any event for most higher level math courses. This skill is also taught in Math 22, 23 and Math 25, and in a few other 100 level courses.
- Math 102: Math 102 is a special spring semester course taught only in 2019 that will introduce students to theoretical mathematics (much like Math 101) via the work of Leonard Euler. It was taught twice before to *great* acclaim. Math 102 also gives a good background for understanding rigorous mathematical arguments and proofs.

Courses in Mathematics

(2018-2019)

This document gives a brief description of the various courses in calculus and some of the intermediate level courses in mathematics. It provides advice and pointers for planning your course selections. If you are a Mathematics Concentrator, or are consid- ering entering the Mathematics Concentration, and if you are seeking some overview of the courses and how they fit together, then this document is for you. However, the guidelines presented below are exactly that: guidelines. Keep them in mind when you are deciding how to structure your program, but be sure to talk to your advisor in the Mathematics Department or to the Director of Undergraduate Studies before you turn in your study card each semester.

1 Calculus

Math 1a/b is the standard first-year calculus sequence. If you are thinking about majoring in math and have not taken calculus before, take Math 1 as soon as possible! If you have had a year of calculus in high school, and if you have passed the Advanced Placement examination in BC Calculus with a score of 4 or better, then you may be advised to begin with Math 21 a/b, the second-year calculus sequence.

If you scored a 5 on the BC Calculus exam and if you are advised to take Math 21 a/b, then you may wish to consider taking Math 22 or 23 or Math 25 or 55 instead of Math 21. Be warned: Math 25 and 55 are intense but very rewarding courses, and both 25 and 55 require extensive work outside the classroom. To succeed in the latter two, you must like doing mathematics for its own sake. (Math 22 and Math 23 require less by way of outside time commitment.)

Regardless of which calculus course you take, keep in mind that it is important to absorb ideas thoroughly. It's a bad idea to push yourself too far too fast.

For more guidance on choosing your first math course at Harvard please read the pamphlet "Beyond Math 1: Which math course is for you?", which you can obtain from Cindy Jimenez, the Undergraduate Program Coordinator (room 334), or from the undergraduate section of the Department's web site.

2 How to structure a good program

No single program is ideal for all math concentrators. You should design your curriculum based on your background, interests, and future plans. You are strongly urged to consult with your academic advisor or with the Director of Undergraduate

Studies in deciding which courses are best suited for you. Do not plan to meet with your advisor on the

day study cards are due, since advisors usually don't have more than a few minutes to spend with each student that day. Make an appointment with your advisor well before study cards are due. You should allot about half an hour, so you can discuss your plan of study in depth.

Learning to write proofs

Math 22, 23, 25, 101, 102, 112, and 121 are seven courses in which you learn to write proofs, meeting (often for the first time) a style of mathematics in which definitions and proofs become part of the language. Students are generally advised not to take any upper-level math courses before completing (or, at least, taking concurrently) one of these.

- Math 101 serves three main goals. It lets a student sample the three major areas of mathematics: analysis, algebra, and topology/geometry; it introduces the notions of rigor and proof; and it lets the student have some fun doing mathematics. If you are considering concentrating in Mathematics but are not sure that you are up for Math 22, 23, 25 or 55, or if you simply want a glimpse of what "higher" math is all about, you are urged to include Math 101 early in your curriculum. Math 101 can be taken concurrently with either Math 21a or 21b or Math 22a. (This course is only offered in the fall.) If you have had some experience with rigorous proofs and want a different taste of "higher" math, you might consider Math 152 in the fall. Neither Math 101 nor Math 152 is appropriate for people from Math 25, Math 55 or (with rare exceptions) Math 23. People who took Math 22 can freely take Math 101 and 152.
- Math 102 is a special course offered just in the spring of 2019. It will also introduce the notions of rigor and proof in Mathematics, but via a study of the mathematics of Leonard Euler. (Euler is perhaps the most influential mathematician of all time.) This course has historical and biographical elements, but its primary purpose is to introduce students to rigorous mathematics through the work of an undisputed master of the subject. It was taught twice before to great acclaim. Prerequisites for Math 102 are a thorough understanding of the first year calculus material (Math 1a and Math 1b). It is open to all students with this background.
- Math 22, 23, 25 and 55 are the four introductory courses for students with strong math interests. They are geared towards new students. Math 25 and 55 are much more intensive than Math 22 and Math 23, but require much more out of class time. Students who don't wish to make the time commitment will do well to choose either Math 22 or Math 23. Meanwhile Math 55 should be taken only by students with *extensive college level math backgrounds*. Each year several first-year students ask to skip the Math 25/55 level and start with Math 122 or another 100-level course. The Department, based on many years of experience, *strongly discourages* this.

Even if you have taken several years of math at another university, even if you have 'seen' every topic to be covered in Math 25 or 55, you will not be bored in these accelerated courses. The topics covered in Math 25 and 55 are not as important as the level and the depth of mathematical maturity at which they are taught. Taking Math 25 or 55 is the most intense mathematical experience you are going to have in any Harvard course, shared with the most talented of your peers. You may learn more advanced material in other 100- and 200-level courses, but never with the same speed and depth as in Math 25 or 55. These courses are not taught in any other university because no other university has the same caliber of first-year mathematicians. And the courses are simply a lot of fun. Many students who have skipped 25 and 55 have been dissatisfied with their decision. In any event, you *must* speak with the Director of Undergraduate Studies if you plan to skip the Math 21-55 level.

- Math 112 and Math 121 are courses suitable for students from Math 21, and they provide an alternative entry-point for the department's more advanced courses in analysis and algebra respectively. Math 112 should not be normally be taken by students who have been through Math 23 or 25 or 55; and Math 121 should not be taken by students who have had one of the four courses Math 22b, 23a, 25a or 55a. (Math 22a,b people can take Math 112, and Math 22a people who take Math 21b can take Math 121). If you are a sophomore and have taken Math 21 but are not yet comfortable with writing proofs, then consider including these courses in your plan of study.

Key courses at the 100 level

If you have taken Math 22, 23, 25 or 55, or if you have taken Math 21 and gained some experience in writing proofs through courses such as Math 101, 102, 112 and 121, then you are ready to take some of the courses at the 100-level that form the core of the Mathematics curriculum. Most of the courses at this level can be classified as belonging to one of the three main streams of mathematics: "analysis", "algebra" and "geometry and topology". Courses belonging to these areas are numbered in the ranges 110–119, 120– 129 and 130–139 respectively. In each stream, there are two courses which are regarded as "core" courses, making a total of six central courses. These are:

- Math 113. Analysis I: Complex Function Theory
  Math 114. Analysis II: Measure, Integration and Banach Spaces
- Math 122. Algebra I: Theory of Groups and Vector Spaces
  Math 123. Algebra II: Theory of Rings and Fields
- Math 131. Topology I: Topological Spaces and the Fundamental Group
  Math 132. Topology II: Smooth manifolds

It is not necessary to include all six of these courses in your plan of study, but here are some points to bear in mind.

- Students from Math 55 will have covered in Math 55 the material of Math 122 and Math 113. If you have taken Math 55, you should look first at Math 114, Math 123 and the Math 131-132 sequence.
- With the exception just noted, you should consider including Math 122 early on in your curriculum. Algebra is a basic language of modern mathematics, and it is hard to comprehend advanced material without some familiarity with groups and related topics in algebra. The same remark applies to Math 123, to a lesser degree.

By the same token, Math 113 should also be taken early on as complex analysis is used in many other fields of mathematics. You will also find the topology you learn in Math 131 useful in many other areas: amongst other things, it provides the mathematical language with which to discuss continuity and limits in wide generality.

- Math 123 cannot be taken before Math 122; but in the other two streams, the courses can be taken in either order. Thus, Math 114 can be taken before or after Math 113, and the same applies to Math 131 and 132.

- You should try to fulfill the *distribution requirement* (i.e., the requirement to take at least one course in analysis, algebra, and geometry/topology) early in your academic career. By your junior or senior year, you should be exposed to the main branches of mathematics; then you can choose the department's advanced courses. In any case, most 200-level courses assume (at least informally) familiarity with the basic tools of analysis, algebra, and topology.

Other courses at the 100 level

At this level, there are many other courses to choose from: Number theory in Math 124 or Math 129, Differential Geometry in Math 136, Probability in Math 154, Logic and Set Theory in Math 141 and Math 143, amongst others.

- It is a good idea to take a tutorial (Math 99r) during the sophomore or junior year. (Note that tutorials are not required.) Many students found the tutorial to be one of the best courses they took at Harvard. Tutorials generally satisfy the Mathematics Expository Writing requirement and often lead to senior thesis topics. More about tutorials appears below.

- Students wishing to take a rigorous course in mathematical logic in years when Math 141 or 145 are not offered at Harvard should consider taking logic courses at M.I.T. In any event, the Harvard courses offer a good introduction to model theory, set theory and recursion theory — the three main branches of Mathematical Logic. Students interested in the more philosophical aspects of logic and/or in proof or set theory may want to take Philosophy 143, and those interested in mathematics of computation should look into Computer Science 121 and some of the other theoretical CS courses.

- Students interested in Combinatorics should look at Math 155, and may also want to look up M.I.T.'s listings in that area. If you want M.I.T. courses to count for the concentration credit, you must get permission in advance from the Director of Undergraduate Studies.

- Students are encouraged to take courses from a variety of professors in the department and not just to "follow" one teacher. It is advisable to be exposed to different views and styles of doing mathematics.

200-level courses

100, 200 – What's the Difference?

The difference between 100-level and 200-level courses is fairly easy to summarize: 100-level courses are designed for *undergraduates,* whereas the 200-level courses are generally designed for *graduate* students. As far as course material goes, the 100-level courses are designed to offer a comprehensive view of all the major fields in pure mathematics. They emphasize the classical examples and problems that started each field going and they all lead to one of the fundamental results that motivates the further development of the field. In contrast, a 200-level course will assume you understand the basic ideas of a field. A 200-level course will set out the systematic, abstract foundations for a field and develop tools needed to get to the present frontiers.

The 100-level courses give you a good overview of mathematics, they foster intellectual growth, and they prepare you for your chosen career. This is not true of 200-level courses. These courses assume that you are interested in the subject, and that you are already fairly certain of becoming an academic mathematician. The amount you learn in such a course is often also entirely up to you. Your prerequisites, though correct according to the course catalog, may be entirely inadequate. Many courses are paired into 100-level and 200-level sequences:

Corresponding 100-level, 200-level Courses

Math 114	⟶	Math 212a,b	(Real Analysis)
Math 113	⟶	Math 213a,b	(Complex Analysis)
Math 122/123	⟶	Math 221	(Algebra)
Math 129	⟶	Math 223a,b	(Algebraic Number Theory)
Math 131	⟶	Math 231a,b	(Algebraic Topology)
Math 132/136	⟶	Math 230a,b	(Differential Geometry)
Math 137	⟶	Math 232a,b	(Algebraic Geometry)

Other 200-level courses are harder to classify, but cover topics equally central to modern mathematics. For example, Math 222 is a course on Lie groups and Lie algebras that draws on background material from analysis, algebra and geometry.

Skipping 100-level Precursors

Students are *strongly* discouraged from taking any 200-level course before taking its 100- level precursors. Although it is possible in principle to learn a general abstract topic on the basis of the logic of its definitions and theorems alone, it is almost impossible to appreciate their significance and "feel" without studying the more down-to-earth background which led to them. *Moreover,* students are well advised to take basic classes in algebra, topology, and analysis before exploring the graduate curriculum: often a basic familiarity with other areas will be an assumed prerequisite. Certainly, it can't hurt. However, even this *may* not suffice.

Some graduate courses (notably 212a, 221a, 231a) often conform better to undergraduate expectations (set material, careful pace, motivation); the best way to tell whether this is going to happen is to go to the class yourself and find out. Beware, though: often these courses start in a user-friendly way (presenting simple definitions, for example), then speed up tremendously as time goes on.

Why Take 200-level Courses?

The reasons for *not* taking 200-level courses are legion. However,there are some equally good reasons for taking them. You will be treated like a graduate student, which is good if you want to be treated like one. There isn't much review of topics you may have already covered, requirements are fairly minimal, and, most importantly, you can learn a lot of substantial mathematics. (If this is what you want, tutorials are another good option. While they are undergraduate courses, one generally learns graduate material in them.)

A student who is considering graduate school in mathematics may want to include at least one 200-level course in his or her program (and, likewise, write a senior thesis) to get a taste of the likes of graduate school.

3 Other types of course

Tutorials

Tutorials are not required, but many students take a tutorial during their sophomore or junior year. Typically two tutorials are offered every semester.

Tutorials (Math 99r) are generally directed by graduate students, and have four to eight students in them. They tend to be less formal and structured than regular courses, yet require more involvement on the part of the students – students have to make presentations and write papers. Very frequently a topic studied in a tutorial leads naturally to a senior thesis. And the paper written for the tutorial generally satisfies the Mathematics Expository Writing requirement.

The department places a description of the fall tutorials into concentrators' registration envelopes in September; a description of the spring tutorials is e-mailed to the concentrators e-mail list in January. Descriptions also appear during the first week of that semester on the undergraduate bulletin boards (one opposite room 320, and one near room 503 in the Math Department). The descriptions also appear on the Math De- partment's website at http://www.math.harvard.edu/. Often, tutorials get previewed at Math Table meetings. A special organizational meeting for tutorials is held in the first week of the fall semester. The spring semester tutorials are organized in the first week of that semester; see the undergraduate bulletin boards for announcements.

Ordinarily only one Math 99r can count towards the concentration requirements.

All questions regarding tutorials may be addressed to the Director of Undergraduate Studies or the Undergraduate Program Coordinator, Cindy Jimenez (cindy@math).

Reading Courses (60r and 91r)

Honors candidates in their last year at Harvard can choose to enroll in Math 60r to allow more time for thesis work. You can take Math 60r in the fall and/or spring semester. Math 60r is SAT/UNS only and does not count for concentration requirements. A student taking Math 60r in the fall must submit a one-page plan of thesis (including at least a preliminary bibliography) to Cindy Jimenez (rm. 334) **by 4 pm** of the last day of the fall reading period in order to pass.

If you want to learn a particular topic not covered in a regular course or a tutorial, you may consider taking Math 91r. To do this, you must find a faculty member willing to supervise your reading, as well as secure approval from the Director of Undergraduate Studies. Make sure that you, your supervisor, and the Director of Undergraduate Studies clearly agree on the topic, structure, frequency of meetings, and the grade requirements before you sign up for 91r. You should know exactly what is expected of you and how much guidance to anticipate. Ordinarily, Math 91r will not count for concentration requirements.

Note that Math 60r, 91r, and 99r require the signature of the Director of Undergraduate Studies on your study card.

Cross-registration at M.I.T.

Students may cross-register to take a course at M.I.T. This may be a useful option in years when a particular course is not offered at Harvard. Logic and Combinatorics offerings at M.I.T. have proven especially popular with Harvard students. Generally, classes at M.I.T. start a week before Harvard's in the fall, and contemporaneously with Harvard's in the spring. You may get concentration credit for M.I.T. courses, but consult

the Director of Undergraduate Studies *before* registering. Cross-registration petitions can be obtained at the Registrar's office or from your House's Senior Tutor.

If you are taking an M.I.T. course, you don't have to walk all the way down Mass. Ave. or even pay for the bus to get to class: you can use the Harvard Medical Area (M2) shuttle bus, which runs from Quincy Square (in front of Lamont) straight to M.I.T.

Related fields

Keep in mind that the concentration requirements for Mathematics require twelve half- courses, but only eight of those need to be listed under "Mathematics" in the Course Catalog. You are encouraged to round out your studies by including courses listed as "Related Fields" in the mathematics section of the *Handbook for Students*.

4 Sample Programs

The programs listed below should not be followed literally – they may not be balanced in workload between the fall and the spring semesters, nor are all the courses listed necessarily offered every year. They are examples designed to demonstrate the range of possibilities. You should determine your own program in consultation with your math faculty advisor or the Director of Undergraduate Studies.

(a) If you start with Math 1 a/b in your first year, you can continue with Math 21 a/b as a sophomore. Students who start with Math 1b in the fall of their first year normally take Math 21a in the spring; some choose also to take Math 21b concurrently with 21a in order to get "in sync." Some students who start with Math 1 a/b sequence freshman year and do extremely well may choose to take Math 22, 23 or 25 their sophomore year instead of Math 21. Otherwise, you'll get a first feel for proofs and abstraction by taking Math 101, 112 or 121. A possible schedule is:

FR	**SO**	**JR**	**SR**
Math 1a	Math 21a	Math 112	Math 113
Math 1b	Math 21b	Math 121	Math 131
CS 50	CS 51	Physics 15a	Math 122
	Math 101	Stat 110	Phil 144

(b) Students who start with 21 a/b in their first year can take 101 either concurrently with Math 21 or in their sophomore year along with with 112, 122 and 131. Students are also encouraged to take Physics 15 a/b/c or Computer Science 51 to broaden their understanding of how mathematics applies to other disciplines. Students who wish to

write a senior thesis often take reading course or a 200-level course in the field of their senior thesis during their senior year.

FR	SO	JR	SR
Math 21a	Math 122	Math 141	Math 231a
Physics 15a	Math 131	Math 124	Math 114
Math 21b	Comp Sci 51	Math 99r	Math 231b
Math 101	Math 112	Math 132	Ec 2052

(c) A student with a strong interest in mathematics, or a strong mathematical background would most likely start with Math 22, 23, 25 or 55 during the first year. His or her sample program might look like this:

FR	SO	JR	SR
Math 22a or 23a or 25a	Math 122	Math 114	Math 60r
Physics 15a	Math 131	Math 99r	Math 212a
Math 22b or 23b or 25b	Math 123	Math 129	Math 222
Physics 15b	Math 113	Math 132	Math 137

(d) Consider a student with a strong interest in mathematical physics, concentrating in Mathematics as a primary field and Physics as the secondary one, and who started with a Math 22a,b or Math 23a,b or Math 25a,b sequence and the Physics 16, 15b, 15c sequence. Some of the 100-level math courses of particular interests to physicists are Math 115, 132 and 136. The sequel to Physics 15c is Physics 143a,b. Choosing some of the math and physics courses with the most conceptual interaction, you might come up with the following to fulfill the math portion of the requirements. (You should consult with the Physics Head Tutor to plan the physics portion.)

FR	SO	JR	SR
Math 22a or 23a or 25a	Math 131	Math 115	Math 230a
Physics 16	Math 122	Math 132 or 136	Math 99r
Math 22b or 23b or 25b	Phys 15c	Physics 143b	Math 230b
Physics 15b	Phys 143a	Phys 181	Math 123

A primary/secondary honors major in Mathematics and Computer Science is com- mon. If you choose this option, you are required to write a thesis which applies ideas of computer science to a topic in pure mathematics, or vice versa. Mathematics courses of particular

value here would be Math 141 (introduction to mathematical logic), Math 124 (number theory including primality tests and applications to codes), Math 130 (on axiomatic foundations of geometry), Math 155 (combinatorics), and Math 152 (discrete mathematics). A possible program when Math is the primary which fulfills the Math requirements is given below. Consult with the Computer Science Head Tutor to plan that portion of your course work.

FR	**SO**	**JR**	**SR**
Math 21a	Math 121	Math 122	Math 141
Math 101	CS 121	CS 207 or 226r	Math 191
Math 21b	Math 112	Math 155	Math 152
CS 51	CS 124	Math 130	Math 124 or AM 111

Math requirements is given below. Consult with the Computer Science Head Tutor to plan that portion of your course work.

FR	SO	JR	SR
Math 21a	Math 121	Math 122	Math 141
Math 101	CS 121	CS 207 or 226r	Math 191
Math 21b	Math 112	AM 107	Math 142
CS 51	CS 124	Math 130	Math 124 or AM 111 or Math 152

Honors in Mathematics
Writing a Senior Thesis
(2018-2019)

Candidacy for Honors

To receive *high* or *highest* honors in Mathematics, a student must submit a senior thesis. A student who wishes to be considered for *straight* honors (neither high nor highest) can either submit a senior thesis or take four extra courses (above the required twelve courses) in Mathematics or approved related fields. If a student submits a senior thesis, then the Mathematics Department recommends the student for graduation with an appropriate level of honors (straight, high or highest or none) based on the course grades in mathematics, the senior thesis and a thesis examination. If a student does not submit a senior thesis but takes the required four extra courses in Mathematics or approved related fields, then the Mathematics Department recommends the student for graduation with straight honors or no honors in Mathematics on the basis of the grades in the student's courses.

The preceding rules are the only requirement for honors eligibility, beyond basic requirements of the Mathematics concentration. The final award of "latin" honors (*cum laude*, *magna cum laude* or *summa cum laude*) is made by the Faculty of Harvard University in accord with rules set forth in *Handbook for Students*, based on the Department's recommendation and a students grades and subject to overall percentage quotas.

Harvard University also awards degrees *cum laude* "on the basis of a student's overall record": that is, on the basis of grades in all subjects. There is no thesis requirement for this version of the *cum laude* degree. Under present faculty rules, students who qualify automatically receive their degrees *cum laude* if they do not receive honors in a field.

You should consult the *Handbook for Students* for a more detailed description of the general regulations relating to honors.

What is an Honors Thesis in Mathematics?

An honors thesis in Mathematics is an original presentation of an area or subject in pure or applied mathematics. A typical thesis is an original synthesis of knowledge culled from a number of sources in the published literature. A thesis can contain substantive, original mathematics, but most do not.

Why Write a Thesis?

The Mathematics Department strongly recommends that its concentrators write a senior thesis. Writing a thesis provides a glimpse of life as a graduate student in mathematics, and as a professionalmathematician. It will also propel you towards the frontiers of current mathematical research. Moreover, working on your thesis can be an opportunity to interact closely with a working mathematician (your thesis advisor), which by itself, offers intellectual rewards.

In the past, almost all the seniors who wrote theses felt that working on one was the most challenging, confidence-raising, and fulfilling experience in their undergraduate careers.

Choice of Thesis Topic

Any subject which makes genuine use of mathematics at the college level is suitable for a senior thesis. The topic may be in pure or applied mathematics, subject to approval from the Director of Undergraduate Studies. In general, a thesis on a rather narrow subject works well, while one presenting the elements of a large theory is less satisfactory both mathematically and in its value to the student. In judging theses more weight is given to the quality of the presentation than to the sophistication of the topic.

Start thinking about possible topics for a thesis early on. Students planning to write an honors thesis are advised to give serious thought to the choice of topic during their junior year. Your courses, your advisor, as well as Math Table lectures, may serve as sources of questions or subjects that interest you. In the past, tutorials and reading courses have proved especially useful in generating ideas leading to a good senior thesis.

It is important to choose a topic which interests you. Without a real interest it is difficult to do the amount of work necessary to write a good thesis. On the other hand, some students search too long for a topic that they will "fall in love" with, ending up with very little time to actually research and write the thesis. (You should merely like a topic or a field of your thesis. Often you simply know too little about the topic at the outset to realistically decide whether it is what you *really* want to study or not. Just don't pick a topic that bores you.) All things being equal, it is best to write a thesis in an area where you have taken several courses or a tutorial already, and therefore, have some perspective.

Thesis Advisor

If you have not chosen a topic on your own before the end of your junior year you should seek the advice of several faculty members as to areas of mathematics suitable for your senior thesis. Math Table is a good source of informal information too. Spend the summer before your senior year reading up in these fields.

At the end of your junior year or at the very start of your senior year, approach a faculty member whose field of expertise covers your chosen topic and consult him/her regarding your plans. Your academic advisor (the person who signs your study card) is usually not your thesis advisor; but he or she may direct you to a faculty member who would be better suited to be your thesis advisor.

All senior theses are written with the explicit advice of a faculty member. A common pattern is to take a reading course (Math 60r, SAT/UNS) during the fall term of your senior year and continue consulting with the same faculty member informally (or again in the context of Math 60r) during the writing of your thesis in the second semester. Note that your thesis advisor can help the department evaluate your thesis when honors decisions are made.

It may be possible to arrange for a professor from MIT or from another department at Harvard to serve as your thesis advisor. However, in such cases the student must have a second advisor in our department, and must get prior approval from the Director of Undergraduate Studies. In the past a few students who were advised solely by faculty from another department ended up with weak theses and did not receive an honors degree.

Therefore, any student whose primary advisor is not a member of the Harvard Math Department is strongly advised to submit to the Director of Undergraduate Studies a complete draft of their thesis 30 days before the final due date for senior theses. This will give the departmental advisor the chance to suggest modifications that can put the thesis into compliance with the department's standards.

As soon as you have decided upon your thesis advisor and the topic, notify the Undergraduate Studies Coordinator, Cindy Jimenez (room 334, e-mail cindy@math).

If you have no topic or no advisor by late September of your senior year, please see the Director of Undergraduate Studies, Cliff Taubes (chtaubes@math), for help.

Getting Help

Choosing a thesis advisor and a topic can be a nerve-racking experience. Furthermore, while working on your thesis you may encounter difficulties, both logistic and otherwise. (For example, some students have trouble defining their goals or circumscribing the thesis topic; some may even decide to change the topic and/or advisor in mid-semester.) In all these circumstances you are encouraged to talk with the Director of Undergraduate Studies, Cliff Taubes, (chtaubes@math).

Enrolling in Math 60r

Seniors can free up time for thesis research by enrolling in Math 60r. You must get the signature of the Director of Undergraduate Studies and you must enroll SAT/UNS. You can enroll for fall, spring, or both semesters. Students enrolled in Math 60r in the fall need to submit a thesis plan to the Director of Undergraduate Studies before the end of the fall reading period (see below).

Plan of thesis

Each candidate for honors in mathematics would do well to submit a thesis plan, one or two pages long, including at least a preliminary bibliography by 4 pm of the last day of the reading period in December to Cindy (rm 334). If you are enrolled in Math 60r in the fall, the failure to submit such a thesis plan by the deadline will result in an unsatisfactory grade for Math 60r.

The Thesis

Originality

An honors thesis in mathematics is not expected to be (and very rarely is) an original contribution to mathematical research. Only originality of presentation is expected. You should study several presentations of your subject until it is thoroughly assimilated and then write your own presentation of the subject. Theses which are drawn from a single source are not acceptable.

Occasionally, students do make original contributions. These are, of course, welcome; but a student is ill-advised to start work on a senior thesis determined to solve some outstanding classical problem. Progress in research is usually made by acquiring a good grasp of existing knowledge and answering successive small questions. If you do discover

something new, be sure to consult with your advisor or some other faculty member about it. He or she may be able to help you go further or protect you from the embarrassment of a serious mistake.

Format

No length or format is prescribed for senior thesis. However, theses exceeding thirty typewritten pages put a considerable strain on the staff and rarely get as much attention as they may deserve. Twenty to twenty-five pages (typewritten) might be considered average; certainly many shorter theses have been judged *summa* quality.

It is not necessary to have your senior thesis typed. A *legible* handwritten thesis is entirely acceptable. However, you may want to typeset your thesis using the math-oriented language LaTeX available on the FAS computer system.

A bibliography *must* be included with your thesis. Please do not forget to put your full name, e-mail address, telephone number, and your thesis advisor's name on the front page of the thesis.

Some old theses are available in Cindy Jimenez's office (rm. 334) for you to look at with regard to style, length and general format.

Deadline

Two copies of the thesis must be handed in to the Undergraduate Studies Coordinator, Cindy Jimenez, in room 334 *no later than 4 pm* on the first Monday after spring recess.

Students Receiving a March Degree or for whom the Fall Semester is their Final Semester

Two copies of the thesis are due by 4 pm on the Monday after Thanksgiving in the office of the Undergraduate Studies Coordinator Cindy Jimenez (rm. 334). Students who wish to plan a timetable for March degree thesis should consult with the Director of Undergraduate Studies, Cliff Taubes (chtaubes@math).

Hoopes Prize

Your advisor may wish to nominate your thesis to the Hoopes Committee for consideration for the Hoopes Prize, which carries substantial monetary rewards for you and your thesis advisor. If you think that your advisor likes your thesis but may not be aware of the Hoopes Prize, don't hesitate to mention to him or her this possibility. In the past, a large portion of theses submitted for this prize from this department have won it. However, be forewarned that even a super Math thesis will fail to win a Hoopes Prize if its introduction (at least) is not written so that a non-mathematician (but scientifically literate individual) can understand it.

The Thesis Examination

Two weeks after you submit your thesis you may inquire with Cindy Jimenez (rm. 334, Cindy@math) as to which faculty member has been nominated to be your thesis reader.

You should then get in touch with your reader to arrange a mutually convenient time for the thesis examination (usually held early in the spring reading period).

Whether the thesis examination will be oral or written will be decided by the thesis reader. If written, the exam will generally be no more than two hours. The aim of the exam is to test whether you have really come to an understanding of your chosen topic. The examination is confined to questions concerning the thesis, direct applications of the thesis, and mathematics related to it. In particular, you are most strongly advised to keep the following very much in mind while writing your thesis and preparing for the thesis exam. No matter how impressively advanced your thesis topic, and no matter how well written your presentation, you will not get a highest honors recommendation if you don't fully understand your subject, or if your understanding is so narrow that you falter on questions that go somewhat to the side of your chosen path through your subject area.

After your thesis has been read and your thesis examination corrected, you may, if you wish, make an appointment to discuss your thesis and the examination with the reader.

Honors Recommendations

Honors recommendations are voted by the Department at a meeting in mid- or late May. Theses and the results of thesis examinations have great weight in formulating these recommendations, but it cannot be precisely quantified; it isn't a matter of simply computing some sort of weighted average. The departmental recommendation may be no honors, honors, high honors, or highest honors. Sometimes the recommendation is conditional on grades in the courses you have just taken.

All candidates for honors are expected to maintain honors-level grades in their math (and related) courses and to have submitted for their senior thesis a clear presentation of material culled from several sources.

A solid, workmanlike presentation, free of substantive errors, will typically receive a recommendation of honors. Students recommended by the department for high honors are expected to have shown insight into the subject and meaningful originality of presentation in their senior thesis and the thesis examination. They are also expected to maintain a high average in their math (and related) courses. In addition to the above, students recommended for the highest honors are expected to have achieved the kind of mastery of the subject generally exhibited by working mathematicians. (They are not required to have proved original results).

Be forewarned that there is, of necessity, a reasonable degree of subjectivity in the Department's decision-making process. The difference between the highest and high honors recommendations is often intangible. For example, highest honors does not require a thesis with original theorems. It requires neither extra course work in Mathematics above the 12-half-course requirement, nor a record with graduate courses. On the other hand, neither a straight A average nor a thesis with original results will ensure a highest honors recommendation from the Mathematics Department. In any event, only a few highest honors recommendations are made in any given year.

Recommendations from the departments are translated by the Administrative Board into recommendation to the Faculty for degrees without honors, *cum laude*, *magna cum laude*, and *summa cum laude*, using criteria explained in the *Handbook for Students*. These recommendations are acted on by the faculty of Harvard University at a meeting preceding the commencement.

In practice, those recommended by the Department for honors or high honors almost

always receive their degrees *cum laude* or *magna cum laude*, respectively, provided their grade-point average is above the relevant cut-offs set forth in the *Handbook for Students*. About two-thirds of those recommended for highest honors graduate *summa cum laude*; the remainder usually receive their degrees *magna cum laude* with highest honors in Mathematics.

Dates to Remember:

- **Sophomore and junior years** – Look for potential thesis topics.
- **End of junior year** – Approach several faculty members for specific suggestions of thesis topics.
- **Summer before senior year** – Read up in the fields of potential thesis topics. Try to make the decision on the topic and become familiar with basic literature on it.
- **September of the senior year** – Choose your thesis advisor. Notify the Undergraduate Studies Coordinator about your choice. Enroll in a reading course supervised by your advisor (optional). (See the Director of Undergraduate Studies, Cliff Taubes, if you have no topic or advisor by the end of September).
- **Last day of the Fall Reading Period** – Submit a thesis plan to the Undergraduate Studies Coordinator Cindy Jimenez by 4 pm.
- **January/February of the senior year** – Start actual writing!
- **March 1**$^{\text{st}}$ – Submit a thesis draft to your advisor for feedback and advice. Submit a draft to the Director of Undergraduate Studies also if your primary advisor is not a member of the Mathematics Department.
- **First Monday after spring recess** (or first Monday after Thanksgiving for students planning to receive a March degree or if the fall semester is their final semester) – Two copies of the thesis are due by 4 pm in the office of the Undergraduate Studies Coordinator Cindy Jimenez (rm. 334).
- **3rd Week of April** – Contact Cindy Jimenez (cindy@math) to find out the name of your thesis reader for arranging a thesis examination.

Graduate Schools and Fellowships in Mathematics

(2018-2019)

Choosing the Right Grad School

Your choice of a graduate school is a major step in your career as a mathematician. Below are some criteria you may consider for choosing the right school for you. Not all the criteria apply to everybody. We strongly urge you to seek advice from several faculty members familiar with you and/or your field of interest early in the fall semester of your senior year to try to sort out what may be the best "fit" between you and a graduate school.

Thesis Advisor

A thesis (dissertation) advisor plays a **very** important role in the student's graduate education. After all, a dissertation generally consists of making a new advance, solving an unsolved problem. And since the problem is not yet solved, the advisor, presumably, has no solution for it either. Therefore it takes a good mathematician, with sound intuition and deep insights to help his/her advisee choose a problem that will, on the one hand, not wind up being so hard that a student can't solve it or parts of it, nor, on the other hand, so easy that a student wouldn't get to learn a lot of beautiful mathematics on his/her way to solving the problem.

Most math departments do not have the resources to excel in all branches of mathematics. You should ascertain that a university you are planning to apply to has top-quality tenured faculty members pursuing research in your potential field of specialization. But you don't necessarily have to go to a leading grad school to get a good advisor. There are a number of mathematics departments in this country which may not be at the top of the pack overall, but which have one or more top-quality mathematicians who can be excellent thesis advisors. Your academic advisor at Harvard can help you sort out which departments are strong in which areas.

Breadth and Depth

As important as it is to choose a school with strong reputation in your field of interest, it is also important to balance this criterion with considerations about the overall breadth of the department. It is common for one's interests to change as learning progresses, and you want to leave yourself the freedom to switch fields or advisors without leaving your chosen graduate department.

The Strength of Your Peers

The quality of other graduate students in the program is also very important. During the first few years of graduate study you will learn much from other graduate students, so it is very helpful to have talented peers.

On the other hand, going to the most competitive school may not be the best decision for everybody. You can sometimes get more time and attention from faculty if you are at the top of a weaker pack, rather than near the bottom of a stronger one. Again, your academic advisor can help you decide what would be best balance in your case.

The Student-to-Faculty Ratio

An equally important factor is the student-to-faculty ratio. In some universities, it is not uncommon to have 10 to 15 grad students working under one advisor. Obviously under these conditions, some students won't get the attention they require.

Visiting the Schools

When making a final decision on graduate schools, **visit** all your serious choices. Talk to faculty members about their research interests and the number of dissertations they are advising. Ask where their former students are employed.

A good source of information are the graduate students currently enrolled in the program. Talk to them about accessibility and reputation of potential advisors in your field of interest. Find out what is the average number of years students take to complete their dissertation, and (very important) what is the dropout ratio. Look into the housing options (very rarely do grad students live in the dormitories for more than a year, if at all) and the teaching load of teaching assistants. Try to decide if you will be comfortable spending some number of years at that university or in that town.

Getting Advice

Finally, you should talk to your academic advisor, the Director of Undergraduate Studies, and other faculty you know well. They can evaluate your choices, give you the latest information about the departments you are considering, and help you decide what is best for you.

Applying to Harvard

The Harvard Math Department encourages its own undergraduates to go elsewhere for graduate study because it is a good idea for a student to get to know other mathematicians, to be exposed to alternative tastes and styles of doing mathematics.

The Admissions Process

Recommendations

An important criterion used by many admissions committees is the content of faculty recommendations. Graduate schools look closely at evidence not only of mathematical ability, but of motivation and tenacity. In contrast to college admissions, extracurricular

activities and non-academic character traits are not given much weight. Usually two or three recommendations are required, and you should be making the effort throughout your undergraduate career to let a few faculty members know you well (e.g., by dropping by their office hours, inviting them to the semi-annual faculty dinners held at your House).

If you are writing a thesis, you might ask your thesis advisor for a letter of recommendation. Working on your thesis during the summer and fall of your senior year with your thesis advisor provides an opportunity for him or her to get to know you better.

If you took a course from a professor and did relatively well, you may want to ask him or her to write a letter of recommendation right away. He or she may not remember all the details of your performance a year or two later. The recommendation can later be fine tuned to address specific graduate schools or fellowships. If you are thinking of taking some time off after college and applying later, you may still want to get your recommendations written while you are in school. Remember that faculty members often take sabbaticals, change universities, etc. Ask your recommenders to send copies of your recommendations to your undergraduate house to be included in your personal folder; they may be useful later on. To place a copy of your recommendation in your undergraduate house file you need to obtain a form from your House's Senior Tutor. Harvard will keep these files indefinitely, and will mail the letters you want to graduate schools or employers at your request.

Essays

You will be required to write one or two application essays. Typically you will need to describe your academic background, your achievements to date, what experiences led you to want to get a Ph.D. in math, and what areas of research interest you most. Those essays give you an opportunity to explain away some bad grades you may have had, to demonstrate your new-found love of math and resolve to succeed, and convince the admissions committee that you not only have the requisite intellect, but that you are going to persevere through some tough moments in your career and finish your dissertation. They want to make sure that you aren't going to grad school just because you could think of nothing better to do, or because you missed the LSAT deadline. You don't have to feel that you should know your dissertation topic by your senior year in college. You should merely demonstrate that you really are interested in mathematics and are relatively focused and determined.

Grades and Test Scores

Besides recommendations and essays, other criteria for admissions include grades and scores on the Graduate Record Examination (GRE). Most selective math departments do not put too much weight on the differences between good and great scores, but having poor grades in math courses or poor GRE scores can hurt your chances of admissions. Many schools look at your transcript to see evidence of substantial exposure to serious mathematics (e.g. some graduate level courses) and are quite understanding about some poor grades.

Taking the GRE

Most universities require applicants to take two parts of the GRE — the general and the subject tests. The general part is similar to the SAT. The questions on the subject test in Mathematics may be quite different from the math most students learn at Harvard, and you are well advised to look over the material tested ahead of time. Even if many of the problems may seem easy, you have less than a minute per question, and if you have to derive everything, you won't finish the test.

GRE, at least in the usual "paper and pen" format, is offered only 3 times a year: in October, December and April. Although you *can* take both the general and the subject part on the same day, most students prefer not to. Therefore many take at least the general part of the GRE during their junior year. In any case, it's a good idea to get the GRE out of the way soon. When you start working on your thesis and filling out applications for grad schools and fellowships, worrying about the GRE will be the last thing you will want to do.

Also keep in mind that you have to register to take the GRE more than a month in advance; if you want to take the test at a place somewhere near Cambridge, you should get moving several months before the test date. For example, if you plan to take GRE in October, and would prefer to take it in Boston rather than, say, in Swampscott (remember, you have to be there at 8am) you should register as early as July. GRE information pamphlets are available from OCS, from the GSAS admissions office at Byerly Hall. You can also obtain them from ETS web page, http://www.ets.org/index.html or from http://www.gre.org.

Note that if you apply for National Science Foundartion (NSF) Graduate Fellowships, then the NSF will actually pay for your GRE test – provided you take it in December. See the NSF application for more information.

Deadlines

The deadlines for graduate school applications range from early December to early January. Most schools usually require you to complete your application folder by January 1st or 15th. The deadlines for fellowship applications start as early as October.

Fellowships and Financial Aid

Unlike what many people think, **you don't need to pay to go to graduate school in mathematics.** Grad students are usually paid (albeit not much) to study. There are several ways post-graduate education in mathematics is financed.

National Fellowships

A few students are able to win national fellowships. The national fellowships are awarded by various government and private foundations, and some pay rather large stipends plus

tuition for the first three to five years of graduate school. Currently, we are aware of support being offered by the following organizations:

- The National Science Foundation, NSF, is the largest funding agency for graduate work in mathematics, offering both regular Graduate Fellowships and some special ones for minorities. The deadline for submitting the first part of the application is usually in November. NSF will even pay for you to take your GRE's in December!

  The NSF web page is http://www.nsf.gov or go directly to *fastlane*, the electronic fellowship application submission web page, http://www.fastlane.nsf.gov.

- The Fannie and John Hertz Foundation, a private foundation that purports to support only students in "applied physical sciences", but, in reality, often funds study for 5 or more years in many areas of pure mathematics. It also has one of the most lucrative stipends. Their web site is at http://www.hertzfndn.org.

- The Department of Defense. It funds the National Defense Science and Engineering Graduate Fellowships (NDSEG). This is a 3-year fellowship, and it is *not* similar to ROTC — you don't have to promise to serve in the military or have any other special obligations to the government if you win a fellowship. To get the application and information, check their web site at http://ndseg.asee.org. The application deadline is usually the first week of January.

- Canadian students should look to The Natural Sciences and Engineering Research Council (NSERC), which provides scholarships for graduate study. For information check their web site at http://www.nserc-crsng.gc.ca. (NOTE: the deadlines for these lie early in the fall semester!)

Flyers put out by some of these fellowships are posted on the undergraduate bulletin boards–one is opposite room 320 and another is opposite room 503.

The Office of Career Services (OCS) Web site offers useful information for applying to graduate school and for finding sources of funding. Please review the Fellowships section on the OCS Web site at http://www.ocs.fas.harvard.edu/students/fellowships.htm. Also, OCS has a library with information on fellowships, and its staff can help you enormously in your pursuit.

The Harvard Graduate School of Arts and Sciences (GSAS) offers fellowship information online at http://gsas.harvard.edu. The online publication "Financing Graduate Studies" is available to download, and the interactive database "Graduate Guide to Grants" will allow you to search for specific grants and provides contact information, application guidelines and restrictions, and deadlines.

Finally, check the Web sites of the universities where you plan to apply. Like GSAS, many graduate schools offer graduate funding options specific to their institutions.

Generally, undergraduates are urged to try their luck in all nationwide fellowships. Harvard students have been very successful in winning these awards. Some fellowships have early deadlines (as early as October) and some pay more attention to the GRE scores and

grades than university admissions offices.

University Fellowships

A university itself may also offer a number of fellowships for students who will accept its offers of admission. These can be as lucrative as the nation-wide fellowships, and you generally don't need any separate application – your application for admission automatically enters you into the competition.

Teaching Assistantships

Students who do not get fellowships usually receive teaching assistantships. Those generally carry a tuition waiver and a stipend that is sufficient for living expenses in exchange for teaching, grading, or assisting in low-level math courses. (Many departments won't let first-year students teach. These often pay incoming students a stipend, and have them begin teaching in their second year). Some students can get research assistantships which let them stop teaching and concentrate exclusively on research.

Masters Degrees

Few students enter graduate school in mathematics for an M.A. However, if you think that this is something you may want to do, you should discuss your situation with your academic advisor or the Director of Undergraduate Studies. In many schools, masters degrees are awarded only on the route to a Ph.D.; also, students who drop out from a Ph.D. program after a year or two are often able to get the masters degree on their way out (you should check the policies of individual departments). If you are applying for a masters program only, you may have less (in some universities, significantly less) chance of getting financial aid. Some universities do not admit students who want to get a terminal M.A. degree.

Harvard's A.B.–A.M. Degree Program

Harvard students with Advanced Standing may wish to apply for the A.B.–A.M. degree. These students must meet both the academic and course requirements for each of these two degrees. A given course can be counted for only one of the two degrees, i.e., one course cannot meet the requirements for the A.B. degree and then be counted again for the A.M. degree. In addition to the course requirements, any candidate for the A.M. degree in Mathematics at Harvard *must take a special language exam* to demonstrate the ability to read mathematics in either French, German or Russian. These tests are administered by the department only once a semester. For more information on the language exams please contact the Graduate Program Coordinator. Any undergraduate who wishes to apply for the A.B.–A.M. degree must file an application form for the graduate program in mathematics just as any other student files for graduate work at Harvard. For information on the degree, contact the office of Advanced Standing.

Study Abroad

There are many fellowships and scholarships for study abroad. Information about them can be obtained on the Office of Career Services (OCS) website, under "Global Opportunities", or from your House Fellowships Tutor. Particularly useful are the *Guide to Grants* and the *Guide to Study Abroad*, published annually by OCS. Some of the math/science oriented fellowships are the:

- **Churchill Scholarship** (for study at Cambridge University),
- **Herschel Smith Harvard Scholarship** (also Cambridge),
- **Weizmann Institute of Science Scholarship** (the Weizmann Institute in Rehovot, Israel).

In the past, math majors from Harvard have also been particularly successful in competing for the **Marshall Scholarships**, and for the **Fulbright Grants**, especially for study in Israel (it seems that at least one grant a year almost always goes for a math student to study Logic at the Hebrew University of Jerusalem, and Israel is one of the very few countries where one does not have to know the native language in order to receive a Fulbright grant to study there). Application deadlines for some of the these fellowships start as early as September.

Further Information and Advice

For further information and advise about graduate programs and fellowships in mathematics, please talk to the Director of Undergraduate Studies, Professor Cliff Taubes, your faculty advisor or the House Fellowship Advisor. They can greatly assist you in determining what recommendations and information outlined here applies in your case, and may help you get more information. And watch for advertisements from fellowships and graduate programs on the undergraduate bulletin boards.

The AB-AM Degree Program

(2018-2019)

The Department offers the AB-AM degree, which allows students who are *primary* mathematics concentrators to obtain a Masters degree (AM) in Mathematics, in addition to their Bachelors degree (AB) during their four years at Harvard. Note that the program requires a large number of additional courses in mathematics. In most cases, the Department recommends that students should instead take advantage of the many other academic opportunities that the University offers.

Only students with Advanced Standing are eligible to apply for this program, and the Department will only accept Math concentrators who have demonstrated sufficient mastery of undergraduate material. The requirements for the AM are: eight courses in mathematics at the 100 or 200 level, with at least four at the 200 level; and take a reading exam in one of three languages — French, German, or Russian. None of these eight courses can count towards the Mathematics concentration requirements. Students should note that this course requirement is hefty and is often found difficult to fit in a schedule. Students considering a joint concentration or a secondary field are usually advised against doing the AB-AM degree.

Any undergraduate who wishes to apply for this degree must file an application form for the graduate program in mathematics, just as any other student files for graduate work at Harvard. If you are considering going on to graduate school in mathematics, bear in mind that the Masters degree will offer you no advantage.

Timeline and Deadlines

Students interested in pursuing the AB-AM degree should follow this timeline:

1. As soon as possible, and in any case before December of their junior year, students should apply for advanced standing through the Undergraduate Office. Students should also meet with their OUE advisor to have their qualifications checked. https://oue.fas.harvard.edu/advanced-standing

2. Students should then meet with the Director of Undergraduate Studies, Professor Cliff Taubes (chtaubes@math), to have a look at their study plan and decide which courses to “bracket”, that is, which courses will count for the AB (math con- centration) degree, and which will count for the AM degree.

3. Only then can students apply for the AB-AM degree, and they have to apply by December 15 of their junior year. Note that this application is

just like a graduate school application, and requires reference letters amongst other things. Details on the application can be found here: https://gsas.harvard.edu/admissions/apply

4. Acceptance notices are given at the end of January by the GSAS admissions office. If accepted, students can take the language exam in the spring of their junior year, or during their senior year.

For More Information

Further details on the requirements and the application process are available at the GSAS website at http://gsas.harvard.edu/programs-of-study/all/mathematics and from the Graduate Studies Coordinator Larissa Kennedy (lkennedy@math). For questions on bracketing courses and whether it makes sense for you to apply, please contact the Director of Undergraduate Studies, Professor Cliff Taubes (chtaubes@math).