Mathematics – 2015-2016

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Mathematics is the science of order, and mathematicians seek to identify instances of order and to formulate and understand concepts that enable us to perceive order in complicated situations.

Perhaps the most important concept of mathematics is that of function, which provides us with the means to study dependence and change. The study of real functions of a real variable (and later complex functions), particularly in connection with the limit concept, is called analysis. The most effective tool for this study is the infinitesimal calculus that analyzes the relation between functions and their derivatives. The study of number systems and their generalizations is called algebra. Here the primary concepts are group, ring, field, and module. The last great branch of mathematics is geometry, which now goes far beyond the classical study of the space we live in to include spaces of high dimension and topology, the abstract theory of shape.

Pure mathematics is concerned with these concepts and their interrelationships, while applied mathematics considers the relation of mathematical concepts to problems arising in other disciplines. Applied mathematics is not a single subject; rather it is almost as many different subjects as there are other disciplines. (But it would be a mistake to think that applied mathematics is organized in terms of the disciplines to which it is applied.)

The concentration in Mathematics is designed to acquaint the student with the most important general concepts underlying the three branches of modern mathematics. Concentration in mathematics will provide an adequate basis for further study in either pure or applied mathematics. Because so many disciplines now rely on the mathematical sciences, a concentration in mathematics provides a valuable background for many different careers. Concentrators who do not choose to continue in mathematics have often gone on to graduate work in other academic subjects or to professional training in law, business, or medicine.

Concentration in Mathematics requires a minimum of either twelve letter-graded half-courses or eleven letter-graded half-courses plus one freshman seminar, subject to the following conditions: Eight of the letter-graded half-courses must be listed as courses taught by the Mathematics Department while the remaining half-courses can be either mathematics courses or courses in approved, related subjects. These eight mathematics courses must include at least one course in analysis, one in algebra or group theory, and one in geometry or topology (all at the 100 level or higher). Tutorials (Math 99r) are encouraged, but not required. Ordinarily no more than one Math 99r course may count toward the concentration requirement. Reading courses, Math 91r, and Math 60r (the latter for senior thesis research only; SAT/UNS only), can be arranged, but do not ordinarily count toward concentration requirements. A Freshman Seminar can be used in lieu of one of the twelve letter-graded half-courses in mathematics or related fields if it is

taught by a faculty member of the Mathematics Department and if permission to do so is obtained from the Director of Undergraduate Studies in Mathematics.

Each student is required to submit a five-page expository paper in mathematics. The paper should be an original, coherent, and correct exposition of a topic in pure or applied mathematics. The paper should be written during the sophomore or junior year under the supervision of a professor or tutor in a tutorial (Math 99r), a Math 91r reading course, or a 100- or 200-level course that the student is contemporaneously enrolled in. The paper must be accepted by both that professor or tutor and the Director of Undergraduate Studies. Ordinarily students enrolled in a tutorial automatically satisfy the expository requirement as part of the structure of the tutorial. The expository requirement must be met before the end of the Reading Period of the second term of the junior year. Extensions may only be granted by the Director of Undergraduate Studies.

A candidate for honors must, in addition to the course requirements, submit a senior thesis. The thesis may be on any topic in pure or applied mathematics not directly covered in a student's course work. It need not be an original piece of mathematical research, but should be an original exposition of material culled from several sources.

In addition, the department offers a Mathematics and Teaching option designed for students who are enrolled in the Undergraduate Teacher Education Program (UTEP). Students who choose this option will acquire eligibility for the teaching certification required for public school teaching in many states.

The department encourages students to take the most advanced courses for which they are qualified. Nevertheless, students who enter as freshmen or Advanced Standing sophomores will not ordinarily be permitted to count courses taken elsewhere toward the twelve half-course requirement. Transfer students wishing to concentrate in Mathematics should consult the Director of Undergraduate Studies, who will review their transcripts and arrange their concentration requirements.

The department welcomes students who want to change their concentration to Mathematics as long as it is plausible that they can fulfill the requirements within the time remaining. Students considering Mathematics may also wish to consider Applied Mathematics, Computer Science, or Statistics. Joint concentrations with Computer Science, Philosophy, Physics, or other fields can be arranged.

REQUIREMENTS

Basic Requirements: 12 half-courses

1. *Required courses:*
    a. Eight letter-graded half-courses in Mathematics, at least four of which must be at the 100 level and including at least one in each of the areas of analysis (numbered 110–119), algebra (numbered 120–129), and geometry (numbered 130–139). Appropriate graduate-level courses may be substituted for these area requirements. Courses listed in the course catalog in other departments which are cross-listed by the Mathematics Department do not count towards this requirement but may count toward requirement 1b.
    b. Four letter-graded half-courses in either Mathematics or related subjects. Related courses include:
        i. Applied Mathematics 21a, 21b, 50 (may not be counted in addition to Mathematics 99r or a Freshman Seminar), 101, 104, 105, 106 (may not be counted in addition to Mathematics 122), 107, 111, 115, 120 (may not be counted in addition to Mathematics 121), 147, 201, 202, 205, 207, 210, 211. Neither Applied Mathematics 21a nor 21b may count toward requirements 1a or 1b in addition to any of the following half-courses: Mathematics 18, 19a, 19b, 21a, 21b, 23a, 23b, 25a, 25b, 55a, 55b.
        ii. Astronomy, 150, 193.
        iii. Organismic and Evolutionary Biology 173, 181, 252.
        iv. Chemistry 160, 161, 242.
        v. Computer Science 51, 121, 124, 187, 220r, 221, 222,223, 225, 226r, 228, 277.
        vi. Economics 1052, 2010a, 2010b, 2010c, 2052, 2120.
        vii. Engineering Sciences 123, 125, 145, 156, 181, 201, 202, 203, 209, 210, 220, 241, 255.
        viii. Philosophy 140, 144
        ix. Physical Sciences 12a, 12b
        x. Physics or Applied Physics, all except 90r, 91r, 95, 120, 129, 136, 140, 141, 141a and courses which are primarily laboratory courses such as 123 and 191.
        xi. Statistics 110, 111, 139, 140, 170, 171, 210, 211, 215, 220, 221.
        Many other courses are given in the University that make substantial use of mathematics. Such courses may be counted as related for concentration credit if approved by the Director of Undergraduate Studies. Students must secure approval for courses not listed in item 1b before filing their study cards.
    c. One Freshman Seminar (graded SAT/UNS) can be substituted for one of the twelve letter-graded half-courses listed in parts 1a and 1b above provided that the following three conditions are met:

i. The Freshman Seminar is taught by a faculty member of the Department of Mathematics.
ii. The Freshman Seminar is not used in lieu of one of the required 110–119, 120–129, or 130–139 courses noted in 1a above.
iii. Permission is obtained from the Director of Undergraduate Studies in Mathematics before the approval of the Plan of Study. A grade of SAT in the seminar is a necessary but not sufficient condition for such permission.
iv. Ordinarily, a Freshmen Seminar may not be counted in addition to another seminar or tutorial course, such as Mathematics 99r.

d. Each student is required to submit a five-page expository paper in mathematics. The paper should be an original, coherent, and correct exposition of a topic in pure or applied mathematics. The paper should be written during the sophomore or junior year under the supervision of a professor or tutor in a tutorial (Math 99r), a Math 91r reading course, or a 100- or 200-level course that the student is contemporaneously enrolled in. The paper must be accepted by both that professor or tutor, and the Director of Undergraduate Studies. Ordinarily students enrolled in a tutorial automatically satisfy the expository requirement as part of the structure of the tutorial.

   The expository requirement must be met before the end of the Reading Period of the second term of the junior year. Extensions may only be granted by the Director of Undergraduate Studies.

2. *Tutorial:* None are required, but Math 99r is suggested. Although Math 99r may be repeated, only one tutorial will count for concentration.
3. *Thesis:* None.
4. *General Examination:* None.
5. *Other information:*
   a. Exceptional programs are frequently approved, especially for students doing advanced work. Consult the Director of Undergraduate Studies.
   b. A student whose record does not include a course in calculus may be asked to demonstrate his/her familiarity with this subject by a special examination.
   c. Mathematics 91r will not ordinarily be counted for concentration credit.
   d. Mathematics 60r will not be counted for concentration credit.
   e. Mathematics Ma and Mb together count as one half-course of concentration credit.

Requirements for Honors Eligibility: 12 half-courses plus thesis

1. *Required courses:* Same as **Basic Requirements**.
2. *Tutorial:* Same as **Basic Requirements**.
3. *Thesis:* Required of all honors candidates.
4. *Special Examination:* A special examination on the area of mathematics germane to the thesis is required of all honors candidates.
5. *General Examination:* None.
6. *Other information:* Same as **Basic Requirements**.

Requirements for Joint Concentrations

The requirements in Mathematics for a joint concentration differ according to whether Mathematics is the primary or allied field. If Mathematics is first, then the requirements are the same as the Requirements for Honors Eligibility as described above. If Mathematics is second, then the requirements are 5 half-courses in Mathematics, at least three of which must be at the 100 level and include at least one in each of the areas of analysis (numbered 110- 119), algebra (numbered 120-129), and geometry (numbered 130-139). For a joint concentration in which Mathematics is second, no expository paper is required.

MATHEMATICS AND TEACHING OPTION

This option is offered by the Department of Mathematics to encourage students with a degree in mathematics to enter secondary school teaching. It is designed for undergraduates who are enrolled in the Undergraduate Teacher Education Program (UTEP). Students who complete UTEP will thereby obtain eligibility for the teaching certificate required for public school teaching by about thirty states, including Massachusetts. See Chapter 2 for more information on UTEP.

***Note**:* Those who plan to teach only in **independent** schools will not need a teaching certificate, and hence do not need to take this program. However, they too may wish to take UTEP courses to enhance their career preparation.

Requirements for Mathematics and Teaching Option: 12 half-courses

1. *Required Courses:*
    a. Seven letter-graded half-courses in Mathematics, including at least one in each of the areas of analysis (numbered 110-119), algebra (numbered 120-129), and geometry (numbered 130-139). Mathematics 101 or 102 can be used to fulfill any one (but only one) of these area requirements. Courses listed in the course catalog in other departments which are cross-listed by the Mathematics Department do not count toward this requirement.
    b. Graduate School of Education (HGSE) T-300a or equivalent practicum in the teaching of Mathematics.
    c. Three letter-graded half-courses in computer science, statistics, or physics, with at least two half-courses in the same field. The courses that can be used to satisfy this requirement include the courses listed in **Basic Requirements** item 1b (v, x, and xi), and, in addition, Computer Science 50 and Statistics 100, 101, 102, 104.
    d. One Freshman Seminar or one letter-graded half-course in Mathematics or a related field in addition to those chosen in 1a and 1c, above. Related courses include all the courses listed in **Basic Requirements** 1b, and also Computer Science 50 and Statistics 100. A course in the history of science may be included with the prior permission of the Director of Undergraduate Studies. The Freshman Seminar can be used for this requirement provided the conditions listed in **Basic Requirements** are met.
    Note: Other courses in statistics or applied mathematics offered in the Harvard Graduate School of Education or in the Graduate School or Arts and Sciences may count as related courses with the approval of the Director of Undergraduate Studies.
2. *Tutorial:* Same as **Basic Requirements**.
3. *Thesis:* None.
4. *General Examination:* None.
5. *UTEP:* The course and teaching requirements of the Undergraduate Teaching Education Program must be completed before graduating under the Mathematics and Teaching option. See Chapter 2 for more information.
6. *Other information*: Interested students are encouraged to inquire about the program at any time. Questions should be directed to the UTEP Associate Director, who is responsible for advising program participants. For further information please contact the Teacher Education Office at the Graduate School of Education, Longfellow Hall, (617-495-2783) beth_simpson@gse.harvard.edu, or visit the UTEP website (www.utep.fas.harvard.edu).

ADVISING

Concentrators are assigned a faculty member to act as their concentration adviser when their Plan of Study is approved by the Director of Undergraduate Studies. Advisers assist concentrators in selecting courses and also sign study cards. In addition, each junior will be asked to meet privately at some point during the academic year with two faculty members to discuss academic progress and career goals.

For up-to-date information on advising in Mathematics, please see the Advising Programs Office website: www.apo.fas.harvard.edu

RESOURCES

The department common room (fourth floor, Science Center) is open to all concentrators and friends of the Mathematics Department. The department library (third floor, Science Center) is open to all concentrators during regular hours (Monday through Friday, 9–5). The library may be used at other hours by seniors writing theses and by other math concentrators with permission from the department.

HOW TO FIND OUT MORE

Six pamphlets are available at the Mathematics Department: Concentration in Mathematics describes the resources of the department; Courses in Mathematics may be useful in the selection of a study plan; Beyond Math I focuses on the differences among the 20-level math courses; Honors in Mathematics gives details of the procedure for writing a senior thesis; Graduate Schools and Fellowships in Mathematics may be useful in formulating graduation plans; Mathematical Sciences at Harvard, published by the School of Engineering and Applied Sciences, describes the resources, courses, and concentrations available to undergraduates interested in pure or applied mathematics. These pamphlets can be obtained from the Undergraduate Studies Coordinator, Cindy Jimenez, Science Center Room 334, 617-495-9116, cindy@math.harvard.edu. Other information about the concentration and the department can be found on the Internet at www.math.harvard.edu.

All questions about the Mathematics concentration should be directed to the Director of Undergraduate Studies, Professor Jacob Lurie, Science Center Room 514, 617-495-9493. Information about tutorials, jobs, fellowships, and other matters is posted on the undergraduate bulletin board opposite Science Center Room 320. All math concentrators are urged to subscribe to the department's undergraduate electronic news network by sending their email addresses to Cindy Jimenez, (cindy@math.harvard.edu).

Mathematical Sciences

The secondary field in Mathematical Sciences is jointly sponsored by the Mathematics Department and the Applied Mathematics concentration.

Requirements: 4 half-courses

Four courses in either Mathematics, Applied Mathematics, or Statistics of which at most two can be in Statistics. The Mathematics and Applied Mathematics courses must be numbered 104 or higher; and Statistics courses must be numbered 110 or higher.

Other Information

Courses must be taken for a letter grade and cannot be taken Pass/Fail. Only courses with a grade of C- or above can be counted.

Students who study abroad or take courses within Harvard Summer School can count course credits toward the secondary field by petitioning for such course to be counted as the equivalent to an approved, Harvard course.

Note that courses in other departments that are only cross listed in the course catalog, under Mathematics, Applied Mathematics or Statistics, will count towards secondary field.

Advising Resources and Expectations

Students interested in pursuing a secondary field in Mathematical Sciences should contact the Director of Undergraduate Studies for Mathematics, Jacob Lurie (lurie@math.harvard.edu), or for Applied Mathematics, Michael Brenner (brenner@seas.harvard.edu).