

# MATHEMATICS

See also Applied Mathematics

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Mathematics has many aspects: it is the language and tool of the sciences, a cultural phenomenon with a rich historical tradition, and a model of abstract reasoning. The course offerings and the major in Mathematics reflect these multiple facets. The Mathematics major provides a broad education in various areas of mathematics in a program flexible enough to accommodate many ranges of interest. Incoming students are encouraged to visit the Math introductory courses guide for advice about choosing their mathematics courses.

## PREREQUISITE

The prerequisite for both the B.A and B.S. degree programs is single variable calculus, through the level of MATH 1150 or equivalent (such as a score of 4 or 5 on the AP Calculus BC exam).

## CALCULUS PLACEMENT PROCEDURES

The department offers a three-term sequence in calculus, MATH 1120, 1150, and 1200. Students who have not taken calculus at Yale and wish to enroll in calculus must take the mathematics online placement examination. Detailed information is available on the Math introductory courses guide. A calculus advising session will be held prior to registration to answer student questions about placement.

MATH 1120 covers differential calculus and assumes mastery of high school algebra, geometry, and trigonometry. Enrolling students are expected to know the basic definitions of trigonometric functions, inverse functions, factoring quadratic polynomials, and elementary area and volume formulas of plane and solid geometry. Students who could benefit from a review of precalculus are encouraged to consider MATH 1100 and 1110 in place of MATH 1120.

The next course in the calculus sequence is MATH 1150, which covers integral calculus, including sequences and series. It assumes mastery of the content of MATH 1120 or equivalent (AP Calculus AB exam).

MATH 1200 covers multivariable calculus and assumes mastery of the material in MATH 1150 or equivalent (AP Calculus BC exam).

## REQUIREMENTS OF THE MAJOR

See Links to the attributes indicating courses approved for Math major requirements.

**Students are held to the requirements that were in place when they declared their major.** However, with approval from the director of undergraduate studies (DUS), the following requirements, updated for the academic year 2024-2025, may be fulfilled by students who declared the major in a prior term.

**Introductory sequence requirement** Each student is expected to complete Linear algebra with proofs (MATH 2250 or 2260), Real analysis (MATH 2550 or 2560), and Vector analysis or Multivariable calculus (MATH 3020 or 1200).

**B.A. degree program** The B.A. degree program consists of ten term courses in Mathematics numbered 2250-5999, including the senior requirement, but excluding MATH 4700. Graduate courses level 6000 and above may not be counted.

To acquire both depth and breadth in the field, students are required to take at least three courses that carry the "math distribution" attribute (YC MATH Distribution), searchable in Yale Course Search (YCS).

Students are also required to complete MATH 3500 (algebra), and at least one of MATH 3050 (real analysis) or MATH 3100 (complex analysis). It is recommended to complete these by the end of junior year. With prior written permission from the DUS, students who completed similar courses elsewhere may substitute a higher-level course in the same area (typically MATH 3700, 3200, 3150 respectively.)

**B.S. degree program** The B.S. degree program consists of twelve term courses and follows the same requirements as for the B.A. degree, with the addition of at least two advanced term courses in the physical sciences, such as ASTR 4180, ASTR 4300, CHEM 3330, 4700, PHYS 4010 or PHYS 4100, PHYS 4020 or PHYS 4300, PHYS 4400, PHYS 4410, PHYS 4500. Other such courses require the approval of the director of undergraduate studies (DUS); written approval is advised.

**Distinction in the major** To be eligible for Distinction in the Major, a student must have completed MATH 3050 (real analysis), MATH 3100 (complex analysis), and MATH 3500 (algebra) for letter grades.

**The intensive major** Candidates for a degree with an intensive major in Mathematics must take MATH 3050, 3100, and 3500. Intensive majors are also expected to include at least two graduate courses level 5000 or above in the Mathematics department, or equivalent independent study, among their required ten mathematics courses. The two graduate courses simultaneously count as electives toward the major, but cannot be counted toward any specific requirement (such as the distribution requirement). Familiarity with the material of the following courses is prerequisite to graduate courses in each category: *algebra*: MATH 3500 and MATH 3700; *analysis*: MATH 3050, 3100; *algebraic topology*: MATH 3500, 4300.

**Credit/D/Fail** No course taken Credit/D/Fail may be applied toward the requirements of the major.

**Outside credit** Courses taken after matriculation at Yale at another institution or during an approved summer or term-time study abroad program may count toward the major requirements with DUS approval.

#### SENIOR REQUIREMENT

During the senior year, students majoring in Mathematics fulfill the senior requirement by taking any Math course numbered MATH 4800 through MATH 4890. Alternatively, with the consent of the DUS, students may write a senior essay in MATH 4750 under the guidance of a faculty member, which includes both a written and an oral report. Students wishing to write a senior essay should consult the DUS during the previous

semester, and are encouraged to pursue independent study opportunities prior to their senior year, for example through the Mathematics directed reading program or through summer research programs.

#### ADVISING

Students interested in pursuing further study in pure mathematics should include MATH 3020, 3050, 3100, 3500, 3700, and 4300 in their programs, and should consider taking one or more graduate-level courses. Students interested in applications of mathematics should include MATH 3020, 3100, 3500, and a selection of courses from MATH 2410, 2420, 2440, 2460, 2470, 2510, 2600.

**Courses related to mathematics** Each Mathematics major is urged to acquire additional familiarity with the uses of mathematics by taking courses in Applied Mathematics, Computer Science, Engineering and Applied Science, Economics, Philosophy, Physics, Statistics and Data Science, or other departments. With approval from the DUS, up to two math-intensive courses from other departments may be counted among the ten courses required for the major in Mathematics.

**Simultaneous B.S./M.S. degree program** Exceptional students may be able to structure their undergraduate programs to become eligible for a simultaneous master's degree in selected graduate programs. Students must successfully complete relevant graduate course requirements and earn qualitative grades of Honors, High Pass, or Pass. At least two grades of Honors are required, and all grades must average High Pass in order to fulfill requirements for the master's degree.

Interested students should consult with both the DUS and DGS prior to submitting the online application, which is due no later than the last day of classes in their fifth term of enrollment in Yale College. Students should also review the GSAS Degree-Granting Departments and Programs page and select the relevant program for specific requirements and application information.

**Graduate work** Undergraduate students are welcome to enroll in courses at level 5000 and above, after completing the relevant prerequisites. We recommend that students wishing to take graduate classes begin with courses at the level 5000-5999, which are accessible to advanced undergraduates, and can be counted toward undergraduate requirements of the major. Courses level 6000 and above cannot be counted toward undergraduate requirements of the major, but they can earn graduation credit, and be applied toward the graduate requirement of the combined B.S./M.S. degree.

#### SUMMARY OF MAJOR REQUIREMENTS

**Prerequisite** Single-variable calculus through MATH 1150 or equivalent

**Introductory sequence** Linear algebra with proofs (MATH 2250 or MATH 2260), Real analysis (MATH 2550 or MATH 2560), and Vector analysis or Multivariable calculus (MATH 3020 or MATH 1200)

**Number of courses** *B.A.* – 10 term courses numbered 2250-5999 (incl senior req), excludes MATH 4700; *B.S.* – 12 term courses numbered 2250-5999 (incl senior req), excludes MATH 4700

**Specific courses required** *B.A. and B.S.* – MATH 3500; MATH 3050 or MATH 3100

**Distribution of courses** *B.A. and B.S.* – 3 courses in the Math distribution category; *B.S.* – at least two adv term courses in the physical sciences as approved by DUS

**Substitution permitted** With DUS permission, up to 2 math-intensive courses from other depts or programs

**Intensive major** All three of MATH 3050, 3100, 3500; 2 math grad courses level 5000 through 5999 or equivalent independent study counted among the required courses

**Senior requirement** Senior seminar numbered MATH 4800 through 4890, or MATH 4750 with DUS permission