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.

PREREQUISITE
The prerequisite for both the B.A and B.S. degree programs is single variable calculus, through the level of MATH 115 or equivalent (score of 4 or 5 on the AP Calculus BC exam).

CALCULUS PLACEMENT PROCEDURES
The department offers a three-term sequence in calculus, MATH 112, 115, and 120. Students who have not taken calculus at Yale and who wish to enroll in calculus must take the mathematics online placement examination. Detailed information is available on the Math first-year student resources website. A calculus advising session will be held prior to registration, to answer student questions about placement.

MATH 112 covers differential calculus, and assumes mastery of high school algebra, geometry, and trigonometry. Enrolling students are expected to know the basic definitions of the 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 110 and 111 in place of MATH 112.

The next course in the calculus sequence is MATH 115, which covers integral calculus, including sequences and series. It assumes mastery of the content of MATH 112 or equivalent (AP Calculus AB exam).

MATH 120 covers multivariable calculus, and assumes mastery of the material in MATH 115 or equivalent (AP Calculus BC exam).

INTRODUCTORY SEQUENCE FOR THE MATHEMATICS MAJOR
Students wishing to pursue study of mathematics typically enroll in MATH 225 (linear algebra and introduction to proofs), followed by MATH 255 (real analysis).

Most students complete multivariable calculus before enrolling in MATH 225, however, prospective mathematics majors and students with interest in abstract mathematics may consider enrolling in MATH 225 directly after MATH 115 or equivalent, and complete their vector analysis/multivariable calculus requirement with MATH 302.
Students with a strong mathematical background that includes exposure to mathematical proofs are encouraged to consider the intensive version of the introductory sequence, MATH 226 and MATH 256.

Incoming students are encouraged to visit the Math first-year student resources website for advice about choosing their mathematics courses.

**REQUIREMENTS OF THE MAJOR**

**B.A. degree program** The B.A. degree program consists of ten term courses in Mathematics numbered 222 or higher, including the senior requirement (MATH 475 or 480 or 481); excluding, however, MATH 470. To acquire both depth and breadth in the field, students are required to take at least two term courses in each of three of the following five categories: analysis; algebra and number theory; statistics and applied mathematics; geometry and topology; and logic and foundations. Students must also take at least one course in at least two of the three core areas: real analysis, algebra, and complex analysis. Taking courses from all three core areas is strongly recommended. The categories and core areas to which each course belongs are indicated in the course listings.

**Introductory sequence requirement for students in the Class of 2025 and beyond** Each student is expected to complete Linear algebra (MATH 225 or 226), Real analysis (MATH 255 or MATH 256), and Vector analysis or Multivariable calculus (MATH 302 or 120). MATH 222 is not recommended as a substitute for MATH 225 or 226, as it does not provide an introduction to proof writing, which is an essential skill for completing upper level mathematics courses.

**Students in the Class of 2024** who have not yet completed their introductory requirement (MATH 230 and 231, or 120 and 225 and 250) are encouraged to visit the Math curriculum revision website for detailed information about transitioning to the new introductory sequences.

**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 at least two advanced term courses in the physical sciences, such as ASTR 418, 430, CHEM 333, 470, or PHYS 401, 402, 410, 412, 420, 430, 440, 441. 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 at least one course from each of the three core areas.

**The intensive major** Candidates for a degree with an intensive major in Mathematics must take courses in all three of the core areas: real analysis; algebra; and complex analysis. Intensive majors are also expected to include at least two graduate term courses in the Mathematics department, or equivalent independent study, among their required ten mathematics courses. Familiarity with the material of the following courses is prerequisite to graduate courses in each category: algebra: MATH 350 and MATH 370; analysis: MATH 305, 310; algebraic topology: MATH 350, 430; logic and foundations: MATH 270.
Substitutions  With permission of the Math DUS, up to two courses from other departments may be counted towards the required courses. For a list of courses that are typically approved, visit the FAQ page on the Math department website.

Credit/D/Fail  Courses taken Credit/D/Fail may not be counted toward the requirements of the major.

SENIOR REQUIREMENT
During the senior year students majoring in Mathematics normally take the senior seminar (MATH 480 or MATH 481). Alternatively, with the consent of the DUS, students may write a senior essay in MATH 475 under the guidance of a faculty member, and give an oral report to the department. Students wishing to write a senior essay should consult the DUS at least six weeks prior to enrolling in MATH 475, 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 302, 305, 310, 350, 370, and 430 in their programs, and should consider taking one or more graduate-level courses. Students interested in applications of mathematics should include MATH 302, 310, 350, and a selection of courses from MATH 241, 242, 244, 246, 251, 260, and CPSC 440.

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 & Data Science, or other departments. In some instances a limited number of such courses may be counted among the ten courses required for the major in Mathematics, with the approval of the DUS.

Graduate work  Each year the Mathematics and Statistics & Data Science departments offer a large number of graduate courses, some of which are accessible to undergraduates with advanced preparation in mathematics.

Combined B.S./M.S. degree program  Students who, by the end of their senior year, complete the requirements of the department for the M.S. in Mathematics are eligible to receive this degree at their Senior Commencement. Required are: (1) eight additional term courses numbered 500 or higher, most of which must be completed with grades of B or better; (2) passing a written qualifying examination of the student’s choice from analysis, algebra, or topology.

The master’s program is in no sense a substitute for the B.S. program; rather, it is designed to accommodate exceptional students who, by means of accelerated or independent study, can satisfy the department as to their command of the content of the normal undergraduate program by the end of the junior year. Candidates must contact the Mathematics DUS at least two weeks prior to the last day of classes of their fifth term at Yale College. Minimum eligibility criteria include at least seventy-five percent of A/A– grades within mathematics as well as seventy-five percent of A/A– grades overall. For more information on mathematics requirements, please see the B.S./M.S. section of the Math major FAQ. For more information on Yale College
requirements for the program, see Academic Regulations, Section L, Special Academic Arrangements, “Simultaneous Award of the Bachelor’s and Master’s Degrees.”

**SUMMARY OF MAJOR REQUIREMENTS**

**Prerequisite** Single-variable calculus through MATH 115 or equivalent

**Number of courses**  
* B.A. – 10 term courses numbered 222 or higher (incl senior essay), excludes MATH 470;  
* B.S. – 12 term courses numbered 222 or higher (incl senior essay), excludes MATH 470

**Specific courses required**  
* B.A. and B.S. – MATH 225 or MATH 226; MATH 255 or MATH 256; MATH 302 or MATH 120

**Distribution of courses**  
* B.A. and B.S. – 2 courses in each of 3 categories chosen from: analysis; algebra and number theory; stat and applied math; geometry and topology; logic and foundations; 1 course from 2 of 3 core areas chosen from: real analysis; algebra; and complex analysis;  
* B.S. – at least two adv term courses in the physical sciences as approved by DUS

**Substitution permitted** With DUS permission, up to 2 courses from other depts, as specified

**Intensive major** Courses in all 3 core areas; 2 MATH grad courses or equivalent independent study counted among the required courses

**Senior requirement** Senior sem (MATH 480 or MATH 481) or, with DUS permission, senior essay (MATH 475) and oral report