Department of Mathematics

Why study mathematics?

Because mathematics is a framework upon which humanity builds an understanding of the world.

The mission of the Department of Mathematics is to create and teach mathematics, and to develop in all students the capacity to understand, discover, enjoy, and use mathematics.

This is a wide-ranging enterprise that involves:

- Enabling students to experience the value and power of mathematical reasoning;
- Providing for the specific mathematical needs of users of mathematics, e.g., in engineering, computer science, economics, physics, finance, education and other physical and social sciences;
- Providing statewide leadership in the mathematics education of all Kansans from K-12 through graduate school;
- Developing interdisciplinary research with other units which make extensive use of mathematics;
- Fostering a climate conductive to active faculty research and interaction with other departments.

The Mathematics Department offers two undergraduate degrees, a B.A. in Mathematics and a B.S. in Mathematics, as well as an Undergraduate Certificate in Actuarial Science. The B.A. has fewer mathematics course requirements and more general education requirements. The B.S. requires more mathematics courses, an applied mathematics concentration, and fewer general education courses. Students who wish to teach mathematics in high school should pursue a B.A. or B.S. in mathematics while participating in the UKanTeach program. The mathematics department offers two graduate degrees, an M.A. and a Ph.D., as well as a Certificate in Applied Mathematics.

Undergraduate Programs

Placement

Students who have not completed a college-level mathematics course should consult the Placement Table (see below) for Initial Enrollment in Mathematics. For information about the Early and Continuous Enrollment in Math requirement, see the CLAS Degree Requirements page (https://catalog.ku.edu/liberal-arts-sciences/#undergraduatetext).

Students may also take the ALEKS Placement, Preparation and Learning Math assessment (http://math.ku.edu/what-aleks/) to determine their proper initial placement in mathematics courses. Students with college credit in mathematics should enroll according to the credit shown on their transcripts and the stated prerequisites for the courses.

Courses for Nonmajors

Students interested in mathematics as part of a background in the liberal arts should enroll in MATH 115, MATH 125, MATH 105, or MATH 365, and other courses according to their interests. Students preparing to use mathematics as a tool in another field should look at the requirements and recommendations of their schools or departments.

MATH 2 is considered a developmental course by all KU schools and is not counted in the minimum number of hours required for graduation.

Placement Table for Initial Enrollment in Mathematics

KU encourages all entering students to complete 4 years of mathematics in high school, including Algebra I and II, Geometry, Trigonometry, and Analytic Geometry, along the lines of the Kansas Board of Regents recommendations (https://admissions.ku.edu/freshman-requirements-deadlines/college-prep-curriculum/).

Your test score	Eligible to enroll in these mathematics courses
ACT: 28-36 or SAT: 660-800 or ALEKS: 76-100	MATH 002, MATH 101, MATH 103, MATH 104, MATH 105, MATH 115, MATH 125 or MATH 365
ACT: 26-27 or SAT: 610-650 or ALEKS: 61-75	MATH 002, MATH 101, MATH 103, MATH 104, MATH 105, MATH 115, or MATH 365
ACT: 22-25 or SAT: 540-600 or ALEKS: 46-60	MATH 002, MATH 101, or MATH 104
ACT: 16-21 or SAT: 460-530 or ALEKS: 30-45	MATH 002
ACT: 0-15 or SAT: 0-450 or ALEKS: 0-29	KU does not offer a mathematics course below MATH 002. Although students with these scores are not prepared, they will be permitted to enroll in MATH 002. Before enrolling in MATH 002, these students are encouraged to prepare by self-study or by completing a beginning algebra course in high school or community college.

After their initial enrollment in mathematics, students must remain continuously enrolled until they have completed MATH 101 or MATH 104.

Preparation for Graduate Study

Students who plan to attend graduate school in the mathematical sciences should speak to an advisor about the best preparation, depending on their goals. Students planning to enter a general mathematics graduate program are encouraged to take MATH 765, MATH 766, MATH 790, and MATH 791. Some graduate degrees require a reading knowledge of French, German, or Russian.

Preparation for Graduate Study

Students who plan to attend graduate school in the mathematical sciences should speak to an advisor about the best preparation, depending on their goals. Students planning to enter a general mathematics graduate program are encouraged to take MATH 765, MATH 766, MATH 790, and MATH 791.

Graduate Programs

The department offers a graduate program leading to both the M.A. and Ph.D. degrees. A broad range of programs is possible in algebra, analysis, combinatorics, control theory, dynamical systems, geometry, numerical analysis, partial differential equations, probability and statistics.

The Department of Mathematics has a long tradition of excellence. The first Ph.D. granted at KU was in mathematics in the year 1895. Since then, the graduate program has been a central part of the department's research and teaching mission and an important component of its long-term planning. The department's commitment to graduate education has boosted its recent growth in size and enhanced its reputation. Prospective students are encouraged to read additional information (https://math.ku.edu/admission-graduate-program/) online.

Students who are interested in enrolling in graduate level coursework in the Department of Mathematics without formal admission to a graduate program at KU are encouraged to apply for graduate non-degree seeking student status. See the department's admission (https://mathematics.ku.edu/admission-graduate-program/) webpage for further details.

Courses

MATH 1W. College Algebra Workshop. 2 Credits.
This course is designed to help students succeed in College Algebra by providing them with additional instructional time, guided practice sessions and supplemental student success curriculum. Prerequisite: Corequisite: MATH 101. Admission based on math placement criteria.

MATH 2. Intermediate Mathematics. 3 Credits. SWT
Mathematics (primarily algebra) preparatory to MATH 101. Topics include: solving linear equations, inequalities, and system; solving quadratic, radical, and rational equations; and introduction to imaginary numbers. Prerequisite: Two years of high school college preparatory mathematics, algebra and geometry, and a score of 16 or more on ACT mathematics; or a qualifying score on the mathematics placement test. MATH 002 is the lowest level mathematics course offered at the University of Kansas, and does not count towards the 120 credit hours required for graduation. Students not prepared for MATH 101 will be permitted to enroll in MATH 002. However, before enrolling in MATH 002, such students are encouraged to prepare by self-study or by completing a beginning algebra course in high school, community college, or correspondence study.

MATH 5W. Introductory Quantitative Reasoning Workshop. 2 Credits.
This course is designed to help students succeed in MATH 105 by providing them with additional instructional time, guided practice sessions and supplemental student success curriculum. Prerequisite: Corequisite: MATH 105. Admission based on math placement criteria.

MATH 7W. Introductory Statistics Workshop. 2 Credits.
This course is designed to help students succeed in MATH 107 by providing them with additional instructional time, guided practice sessions and supplemental student success curriculum. Prerequisite: Corequisite: MATH 107. Admission based on math placement criteria.

MATH 101. College Algebra: _____. 3 Credits. GE12 SWT MTS
The course comes in the three following forms based on the instructional approach to support different student groups. Standard: The regular version of college algebra. With Practice Workshops: Meets 5 days per week, 4-credit (co-enrollment in the corresponding section of MATH 197 is required). Department permission required to enroll. For students who can benefit from additional review during the course. Students with slightly lower ACT scores may be admitted based on high school GPA. Also recommended for students passing Math 002 with a lower grade. Online: Intended for students who are self-motivated, studying abroad, or who have irregular schedules or alternate class needs. Features: self-driven material, in-person exams. All versions share the same material: coordinate systems, functions and their graphs; linear, quadratic, general polynomial, rational, exponential, and logarithmic functions; equations and inequalities; and linear and non-linear systems. Not open to students with credit in MATH 104. Prerequisite: MATH 002, or two years of high school algebra and a score of 22 or higher on ACT mathematics, or a qualifying score on the mathematics placement test. Students with slightly lower ACT scores may be admitted to With Practice Workshops sections based on high school GPA.

MATH 103. Trigonometry. 2 Credits. SWT
The circular functions and their applications. Not open to students with credit in MATH 104. May not be used to fulfill the College mathematics requirement. Prerequisite: MATH 101, or two years of high school algebra and a score of 26 or higher on enhanced ACT mathematics, or a qualifying score on the mathematics placement test.

MATH 104. Precalculus Mathematics. 5 Credits. GE12 MTS
An introduction to the elementary functions (polynomial, rational, exponential, logarithmic, and trigonometric) and their properties. Open for only two hours credit for students with credit in MATH 101. Not open to students with credit in MATH 103. Prerequisite: MATH 002, or two years of high school algebra and a score of 22 or higher on ACT mathematics, or a qualifying score on the mathematics placement test.

MATH 105. Introductory Quantitative Reasoning. 3 Credits. GE12 MTS
This diverse course introduces students to foundational quantitative reasoning skills that will assist them throughout their college-level work and beyond. Topics may include logic and problem solving, personal finance, elementary statistics and data analysis, voting theory and fair division problems, basic linear programming, and network theory. Students taking this class will gain an appreciation for how mathematical thinking can be used in everyday decision making. Prerequisite: MATH 2, or two years of high school algebra and a score of 22 or higher on ACT mathematics, or a qualifying score on the mathematics placement test.

MATH 107. Introductory Statistics. 3 Credits. SWT MTS
This course introduces fundamental statistical concepts, including descriptive and inferential statistics, graphical and numerical data descriptions, probability calculations, data analysis for observational and experimental data, confidence intervals, hypothesis testing, statistical inference for single and two parameters, and simple linear regression with correlation analysis. Not open to students with credit in DSCI 202, BIOL 370, MATH 365, MATH 465, MATH 526, or MATH 628. Prerequisite: MATH 2, or two years of high school algebra and a score of 22 or higher on ACT mathematics, or a qualifying score on the mathematics placement test.

MATH 109. Mathematics for Elementary School Teachers I. 3 Credits.
This course is designed to give the prospective elementary school teacher an overview of several components of the elementary school mathematics curriculum, including number systems, estimation, inequalities and order, sequences and patterns, sets, and relations and functions. The class meets each week for three one-hour instruction sessions and one two-hour laboratory session. This course may not be used to satisfy the College mathematics requirement. Prerequisite: MATH 101 or equivalent placement.

MATH 110. Mathematics for Elementary School Teachers II. 3 Credits.
Continuation of MATH 109, including geometry (including transformations) and elementary probability and statistics. Class meets each week for three one-hour instruction sessions and one two-hour laboratory session. This course does not serve as a prerequisite for any mathematics course. It may not be used to satisfy the College mathematics requirement. Prerequisite: MATH 109.

MATH 115. Calculus I. 3 Credits. GE12 SWT MTS
Elementary differential and integral calculus, with applications in management and the biological sciences. Not open to students with credit in MATH 125 or MATH 145. Prerequisite: MATH 101 or MATH 104, or two years of high school algebra and a score of 26 or higher on ACT mathematics, or a qualifying score on the mathematics placement test.

MATH 116. Calculus II. 3 Credits.
Continuation of MATH 115 including exponential, logarithmic, and trigonometric functions, techniques of integration, and the calculus of functions of several variables. Not open to students with credit in MATH 127 or MATH 147. Prerequisite: MATH 115 plus a course in trigonometry, or MATH 125 or MATH 145. MATH 103 may be taken concurrently.

MATH 125. Calculus I. 4 Credits. GE12 SWT MTS
Limits, continuity and derivatives of algebraic, trigonometric, exponential and logarithmic functions. Curve sketching, optimization and other applications of the derivative. Antiderivatives, Riemann sums, the definite integral, and the fundamental theorem of calculus. Open for only 1 hour credit to students with credit in MATH 115. Not open for credit to students with credit in MATH 116 or MATH 145. Prerequisite: MATH 103 or MATH 104, with a grade of C- or higher; or 3 years of college preparatory mathematics including trigonometry, with a score of 28 or higher on the ACT Mathematics exam, or a qualifying score on the mathematics placement test.

MATH 126. Calculus II. 4 Credits.
Techniques of integration, including integration by parts. Applications of integration, including volume, arc length, work and average value. Infinite sequences and series and Taylor series. Polar coordinates, vectors and the geometry of space. Open for only 2 hours of credit to students with credit in MATH 116. Not open for credit to students with credit in MATH 146. Prerequisite: MATH 116, MATH 125, or MATH 145, with a grade of C- or higher.

MATH 127. Calculus III. 4 Credits. MTS
Multivariable functions, partial derivatives and their applications, multiple integrals and their applications. Vector-valued functions, line and surface integrals, Green, Gauss and Stokes Theorems. Not open for credit to students with credit in MATH 147. Prerequisite: MATH 126 or MATH 146, with a grade of C- or higher.

MATH 145. Calculus I, Honors. 4 Credits. GE12 MTS
Limits, continuity and derivatives of algebraic, trigonometric, exponential and logarithmic functions. Curve sketching, optimization and other applications of the derivative. Antiderivatives, Riemann sums, the definite integral, and the fundamental theorem of calculus. Open for only 1 hour credit to students with credit in MATH 115. Not open for credit to students with credit in MATH 116 or MATH 125. Prerequisite: An ACT Math score of 34 or higher, or membership in the University Honors Program and an ACT Math score of 32 or higher.

MATH 146. Calculus II, Honors. 4 Credits.
Techniques of integration, including integration by parts. Applications of integration, including volume, arc length, work and average value. Infinite sequences and series and Taylor series. Polar coordinates, vectors and the geometry of space. Open for only 2 hours credit to students with credit in MATH 116. Not open for credit to students with credit in MATH 126. Prerequisite: MATH 125, or MATH 145, with a grade of C- or higher; and invitation of the Department of Mathematics.

MATH 147. Calculus III, Honors. 4 Credits.
Multivariable functions, partial derivatives and their applications, multiple integrals and their applications. Vector-valued functions, line and surface integrals, Green, Gauss and Stokes Theorems. Not open for credit to students with credit in MATH 127. Prerequisite: MATH 126 or MATH 146, with a grade of C- or higher; and invitation of the Department of Mathematics.

MATH 176. First Year Seminar: _____. 3 Credits. USC
A limited-enrollment, seminar course for first-time freshmen, addressing current issues in Mathematics. Course is designed to meet the US Culture of the KU Core 34. First-Year Seminar topics are coordinated and approved by the Undergraduate Education Office within Academic Affairs.

MATH 197. Mathematical Workshops: _____. 1-3 Credits.
Offered to provide opportunities for deeper understanding of freshman-sophomore mathematics through interactive learning. Topics will vary. May be repeated for additional credit. Prerequisite: Variable.

MATH 209. Functions and Modeling. 3 Credits.
Study of the use of functions in mathematical modeling, with topics drawn from algebra, analytic geometry, statistics, trigonometry, and calculus. These topics include function properties and patterns, complex numbers, parametric and polar equations, vectors and various growth models. The course also includes inquiry methods, collaborative problem solving, the use of multiple representations and data analysis techniques, and the justification and presentation of results. Central to the course are investigative labs employing various technologies and software. The course is designed to help prepare students for secondary school mathematics teaching. (Same as PHSX 209.) Prerequisite: MATH 126 or MATH 146.

MATH 220. Applied Differential Equations. 3 Credits.
Linear ordinary differential equations, Laplace transforms, systems of equations, and applications. Not open to those who have taken MATH 320. Prerequisite: MATH 126 or MATH 146 with grade of C- or higher; previous or concurrent enrollment in MATH 290 or MATH 291 recommended.

MATH 221. Applied Differential Equations, Honors. 3 Credits.
Linear Ordinary Differential Equations, Laplace Transforms, Systems of Equations, Enrichment Applications. Prerequisite: MATH 126 or MATH 146 with grade of C- or higher, and invitation from the Department of Mathematics; previous or concurrent enrollment in MATH 290 or MATH 291 recommended. Not open to students with credit in MATH 320.

MATH 290. Elementary Linear Algebra. 2 Credits.
Systems of linear equations, matrices, vector spaces, linear transformations, and applications. Not open to those who have taken MATH 590. Prerequisite: MATH 126 or MATH 146 with grade of C- or higher.

MATH 291. Elementary Linear Algebra, Honors. 2 Credits.
Systems of Linear Equations, Matrices, Vector Spaces, Linear Transformations, Enrichment Applications. Prerequisite: MATH 126 or MATH 146 with a grade of C- or higher, and invitation from the Department of Mathematics. Not open to students who have taken MATH 590.

MATH 296. Special Topics: _____. 1-3 Credits.
Designed for the study of special topics in mathematics at the freshman/sophomore level. May be repeated for additional credit; does not count toward the major or minor in mathematics. Prerequisite: Variable.

MATH 320. Elementary Differential Equations. 3 Credits.
Linear ordinary differential equations, series solutions. Laplace transforms. Systems of equations. Not open to those who have taken MATH 220. Prerequisite: MATH 127 or MATH 147 with a grade of C- or higher, and MATH 290 or MATH 291.

MATH 365. Elementary Statistics. 3 Credits. GE12 SWT MTS

This course will cover elementary descriptive statistics of a sample of measurements; probability; the binomial, Poisson, and normal distributions, populations and sampling from populations; and simple problems of statistical inference. May not be counted for junior-senior credit toward a major in mathematics. Not open to students with credit in DSCI 202, BIOL 370, MATH 465, MATH 526, or MATH 628. Prerequisite: MATH 101, MATH 104, or two years of high school algebra and a score of 26 or higher on ACT mathematics, or a qualifying score on the mathematics placement test.

MATH 409. Topics in Geometry for Secondary and Middle School Teachers. 2 Credits.
Study of selected topics from Euclidean, non-Euclidean, and transformation geometry chosen to give breadth to the mathematical background of secondary and middle school teachers. May not be counted for junior-senior credit towards a major in mathematics. Prerequisite: MATH 126 or MATH 146. Students enrolled in MATH 409 must concurrently enroll in MATH 410.

MATH 410. Topics in History of Mathematics for Secondary and Middle School Teachers. 1 Credits.
Study of selected topics from mathematical history chosen to provide students with knowledge of major historical developments in mathematics including individual contributions and contributions from different cultures. These topics will include a historical development of Euclidean and non-Euclidean geometry. May not be counted for junior-senior credit towards a major in mathematics. Prerequisite: MATH 126 or MATH 146. Students enrolled in MATH 410 must concurrently enroll in MATH 409.

MATH 450. Discrete Mathematics. 3 Credits.
Basic topics in discrete mathematics including sets, logic, relations and functions, graphs and combinatorics. Advanced topics chosen from partially ordered sets and lattices, Boolean algebras, automata, game theory, coding theory, cryptography, optimization and enumeration. Prerequisite: MATH 290.

MATH 500. Intermediate Analysis. 3 Credits.
A careful formulation of convergence and limits of sequences and functions; continuity and properties of continuous functions; differentiation; the Riemann integral; mean-value theorems and the fundamental theorem of calculus. Not open to students with credit in MATH 765. Prerequisite: MATH 127 or MATH 147, and MATH 290 or MATH 291.

MATH 510. Introduction to the Theory of Computing. 3 Credits.
Finite state automata and regular expressions. Context-free grammars and pushdown automata. Turing machines. Models of computable functions and undecidable problems. The course emphasis is on the theory of computability, especially on showing limits of computation. (Same as EECS 510.) Prerequisite: EECS 210 and upper-level EECS eligibility.

MATH 526. Applied Mathematical Statistics I. 3 Credits.
A first course in statistics for students with the techniques of calculus at their disposal. The following topics are studied with illustrations and problems drawn from various fields of applications: basic notions of probability and probability distributions; classical estimation and testing procedures for one and two sample problems; chi-square test. Not open to those with credit in MATH 628. Prerequisite: MATH 127 or MATH 147 or MATH 116 (MATH 127 or MATH 147 recommended.)

MATH 540. Elementary Number Theory. 3 Credits.
Divisibility, primes and their distribution, the Euclidean algorithm, perfect numbers, Fermat's theorem, Diophantine equations, applications to cryptography. Prerequisite: MATH 127 or MATH 147.

MATH 558. Introductory Modern Algebra. 3 Credits.
Development of the number systems. Polynomials. Introduction to abstract number systems such as groups and fields. Not open to students with credit in MATH 791. Prerequisite: MATH 290 or MATH 291.

MATH 559. Modern Geometries. 3 Credits.
Selected topics in Euclidean geometry. Synthetic and analytic projective geometry; duality, Desargues' theorem, perspectives, conics. Non-Euclidean and metric projective geometries. Prerequisite: MATH 127 or MATH 147.

MATH 581. Numerical Methods. 3 Credits.
An introduction to numerical methods and their application to engineering and science problems. Applied treatment of elementary algorithms selected from the subject areas: finding roots of a single nonlinear equation, numerical differentiation and integration, numerical solution of ordinary differential equations. Emphasis on implementing numerical algorithms using the computer. Not open to students with credit in MATH 781 or MATH 782. Prerequisite: MATH 220 and MATH 290, or MATH 320.

MATH 582. Computational Data Science. 3 Credits.
This course provides an introduction to topics in data science and machine learning with an emphasis on computation and applications. Programming for the course uses the student's choice of Matlab, Python, or R. Topics covered include dimension reduction, regression techniques, density estimation, machine learning, data assimilation, and clustering and classification techniques. Prerequisite: MATH 290 or equivalent.

MATH 590. Linear Algebra. 3 Credits.
Vector spaces, linear transformations, and matrices. Canonical forms, Determinants. Hermitian, unitary and normal transformations. Not open to students with credit in MATH 790. Prerequisite: MATH 127 or MATH 147, and MATH 290 or MATH 291.

MATH 591. Applied Numerical Linear Algebra. 3 Credits.
An introduction to numerical linear algebra. Possible topics include: applied canonical forms, matrix factorizations, perturbation theory, systems of linear equations, linear least squares, singular value decomposition, algebraic eigenvalue problems, matrix functions, and the use of computational software. Not open to students with credit in MATH 782. Prerequisite: MATH 290 or MATH 291. EECS 138 or equivalent recommended.

MATH 596. Special Topics: _____. 1-3 Credits.
Arranged as needed to present appropriate material to groups of students. May be repeated for additional credit. Prerequisite: Variable.

MATH 601. Algebraic Topics in Computing: _____. 3 Credits.
Topics motivated by applications in computer science, studied from a mathematical perspective, and based on methods from linear and abstract algebra. Examples of topics include error-correcting codes, cryptography, and computer algebra. May be repeated with different topics for additional credit. Prerequisite: MATH 290 or MATH 291.

MATH 605. Applied Regression Analysis. 3 Credits.
This course provides an introduction to regression analysis and statistical learning with an emphasis on mathematical understanding and its software implementation. Programming uses Python, R, or Julia. Covered topics include the following. Linear regression: parameter estimation, confidence ellipsoids and prediction intervals, hypothesis tests. Classification: logistic regression, linear discriminant analysis. Basis expansion: polynomial regression, regression splines. Resampling methods: cross-validation, bootstrap. Shrinkage methods. Model selection: information criteria, forward and backward selection, lasso. Decision trees and random forests: bagging, boosting. Prerequisite: MATH 290 or MATH 291, and MATH 526 or MATH 628.

MATH 608. Statistical Data Science. 3 Credits.
This course provides an introduction to main statistical concepts in data science with an emphasis on mathematical understanding and its software implementation. Programming uses Python or Julia. Covered statistical models include linear regression and linear classification for high-dimensional problems; support vector machines and flexible discriminants; Bayesian learning and the EM algorithm; Monte Carlo methods; probabilistic graphical models; unsupervised learning. Prerequisite: A calculus-based statistics course (MATH 628 or MATH 526) and a linear algebra course (MATH 290 or MATH 291). Recommended: EECS 138 or equivalent experience.

MATH 611. Time Series Analysis. 3 Credits.
This course provides an introduction to time series analysis with an emphasis on mathematical understanding and its software implementation. Programming uses Python, R, or Julia. Covered topics include the following. Modeling time series, trend, seasonality and residual process. Autocovariance function, multivariate time series, moving average and autoregression. Stationary processes, linear processes, linear filtering. Confidence intervals for the mean and the autocorrelation, hypothesis tests for a time series model. ARMA models, partial autocorrelation function, parameter estimation methods, forecasting, model selection. Stationary processes in the frequency domain, spectral density, periodogram, smoothing, spectral window. Nonstationary time series, ARIMA models. State-space representation, Kalman recursions. Recurrent neural networks as time allows. Prerequisite: MATH 290 or MATH 291, and MATH 526 or MATH 628.

MATH 624. Discrete Probability. 3 Credits.
Theory and applications of discrete probability models. Elementary combinatory analysis, random walks, urn models, occupancy problems, and the binomial and Poisson distributions. Prerequisite: MATH 127 or MATH 147, and MATH 290 or MATH 291.

MATH 627. Probability. 3 Credits.
Introduction to mathematical probability; combinatorial analysis; the binomial, Poisson, and normal distributions; limit theorems; laws of large numbers. Prerequisite: MATH 127 or MATH 147 and MATH 290 or MATH 291.

MATH 628. Mathematical Theory of Statistics. 3 Credits.
An introduction to sampling theory and statistical inference; special distributions; and other topics. Prerequisite: MATH 627.

MATH 630. Actuarial Mathematics. 3 Credits.
This course is an introduction to some of the notions and computations in actuarial mathematics. Many computations are associated with compound interest with applications to bank accounts, mortgages, pensions, bonds, and annuities. Life contingencies are considered for annuities and insurance. Some introduction to option pricing is given, particularly the Black-Scholes formula. This course provides the background material needed for some of the initial examinations given by the societies for actuaries, including the Financial Mathematics Exam. Prerequisite: MATH 526 or MATH 627 or a comparable course in probability.

MATH 646. Complex Variable and Applications. 3 Credits.
Analytic functions of a complex variable, infinite series in the complex plane, theory of residues, conformal mapping and applications. Prerequisite: MATH 127 or MATH 147.

MATH 647. Applied Partial Differential Equations. 3 Credits.
Boundary value problems; topics on partial differentiation; theory of characteristic curves; partial differential equations of mathematical physics. Prerequisite: MATH 127 or MATH 147 and MATH 220 or MATH 221 or MATH 320.

MATH 648. Calculus of Variations and Integral Equations. 3 Credits.
Topics in the calculus of variations, integral equations, and applications. Prerequisite: MATH 127 or MATH 147 and MATH 220 or MATH 221 or MATH 320.

MATH 650. Nonlinear Dynamical Systems. 3 Credits.
This course provides an introduction to nonlinear ordinary differential equations and dynamical systems theory with an emphasis on applications. Topics covered include the existence and uniqueness of solutions to initial value problems, as well as the qualitative behavior of solutions, including existence of equilibria, periodic and connecting orbits and their stability. Additional topics include an introduction to bifurcation theory and chaos. Prerequisite: MATH 127 or MATH 147, and MATH 220 or MATH 221 or MATH 320, and MATH 290 or MATH 291.

MATH 660. Geometry I. 3 Credits.
An introduction to modern geometry. Differential geometry of curves and surfaces, the topological classification of closed surfaces, dynamical systems, and knots and their polynomials. Other topics as time permits. Prerequisite: MATH 127 or MATH 147 and MATH 290 or MATH 291.

MATH 661. Geometry II. 3 Credits.
Continuation of MATH 660. Prerequisite: MATH 660 or permission of instructor.

MATH 690. Capstone in Statistics. 3 Credits.
Integrating and applying theories, concepts and methods from previous statistics courses, students will explore modern statistical methods and will employ them in group or individual projects. Topics and projects will be selected by the instructor. Prerequisite: MATH 628 and completion of at least 29 credit hours of major required courses.

MATH 696. Special Topics: _____. 1-3 Credits.
Arranged as needed to present appropriate material to groups of students. May be repeated for additional credit. Prerequisite: Variable.

MATH 699. Directed Reading. 1-3 Credits. AE61 CAP
Directed reading on a topic chosen by the student with the advice of an instructor. May be repeated for additional credit. Consent of the department required for enrollment.

MATH 717. Nonparametric Statistics. 3 Credits.
Methods requiring few assumptions about the populations sampled. Topics include quantile tests, tolerance limits, the sign test, contingency tables, rank-sum tests, and rank correlation. Prerequisite: MATH 628 or permission of instructor.

MATH 724. Combinatorial Mathematics. 3 Credits.
An introduction to enumerative combinatorics. Topics include basic counting principles, induction and recursion, graph theory, partitions and compositions, generating functions, inclusion/exclusion, and Polya-Redfield theory. Prerequisite: MATH 290 or MATH 291 and a MATH course numbered 450 or higher.

MATH 725. Graph Theory. 3 Credits.
Graphs; trees; connectivity; Menger's theorem; eulerian and hamiltonian graphs; planarity; coloring of graphs; factorization of graphs; matching theory; alternating chain methods; introduction to matroids with applications to graph theory. Prerequisite: MATH 290 and a math course numbered 450 or higher.

MATH 727. Probability Theory. 3 Credits.
A mathematical introduction to premeasure-theoretic probability. Topics include probability spaces, conditional probabilities and independent events, random variables and probability distributions, special discrete and continuous distributions with emphasis on parametric families used in applications, the distribution problem for functions of random variables,

sequences of independent random variables, laws of large numbers, and the central limit theorem. Prerequisite: MATH 290, or equivalent.

MATH 728. Statistical Theory. 3 Credits.
Theory of point estimation and hypothesis testing with applications. Confidence region methodologies and relations to estimation and testing. Prerequisite: MATH 727 or equivalent.

MATH 750. Stochastic Adaptive Control. 3 Credits.
Stochastic adaptive control methods. Stochastic processes such as Markov chains and Brownian motion, stochastic integral, differential rule, stochastic differential equations, martingales and estimation techniques. Identification and control of discrete and continuous time linear stochastic systems. Specific applications and simulation results of stochastic adaptive control theory. Prerequisite: MATH 627 and some knowledge of control.

MATH 765. Mathematical Analysis I. 3 Credits.
MATH 765 and MATH 766 are theoretical courses on the fundamental concepts of analysis and the methods of proof. These two courses include the concept of a real number; limits, continuity, and uniform convergence; derivatives and integrals of functions of one and of several real variables. Prerequisite: MATH 290, or equivalent.

MATH 766. Mathematical Analysis II. 3 Credits.
A continuation of MATH 765. Prerequisite: MATH 765.

MATH 781. Numerical Analysis I. 3 Credits.
Finite and divided differences. Interpolation, numerical differentiation, and integration. Gaussian quadrature. Numerical integration of ordinary differential equations. Curve fitting. Students may not enroll in EECS 639 after enrolling in MATH 781/EECS 781. In addition, students may not simultaneously enroll in MATH 781/EECS 781 and EECS 639. (Same as EECS 781.) Prerequisite: MATH 320 and knowledge of a programming language.

MATH 782. Numerical Analysis II. 3 Credits.
Direct and interactive methods for solving systems of linear equations. Numerical solution of partial differential equations. Numerical determination of eigenvectors and eigenvalues. Solution of nonlinear equations. (Same as EECS 782.) Prerequisite: EECS 781 or MATH 781.

MATH 783. Applied Numerical Methods for Partial Differential Equations. 3 Credits.
Finite difference methods applied to particular initial-value problems (both parabolic and hyperbolic), to illustrate the concepts of convergence and stability and to provide a background for treating more complicated problems arising in engineering and physics. Finite difference methods for elliptic boundary-value problems, with a discussion of convergence and methods for solving the resulting algebraic system. Variational methods for elliptic problems. Prerequisite: MATH 647 or equivalent.

MATH 790. Linear Algebra II. 3 Credits.
A theoretical course on the fundamental concepts of linear algebra. Topics to be covered include: vector spaces, bases, dimension, subspaces, dual spaces; inner product spaces; linear operators on finite dimensional inner product spaces, including self-adjoint and normal operators; spectral theorems over the real and complex numbers; various canonical forms; singular values theorem. Prerequisite: MATH 590 or its equivalent.

MATH 791. Modern Algebra. 3 Credits.
Topics in the theory of groups, rings and fields at the graduate level, including: normal subgroups, isomorphism theorems, examples of finite groups, symmetric groups, class equation, applications of Sylow theorems, integral domains, PIDs and UFDs, algebraic extensions of fields, rudiments of Galois theory. Prerequisite: MATH 558 or consent of the instructor. Previous experience with abstract algebra at the level of MATH 558 is recommended.

MATH 796. Special Topics: _____. 1-3 Credits.
Arranged as needed to present appropriate material for groups of students. May be repeated for credit. Prerequisite: Variable.

MATH 799. Directed Readings. 1-3 Credits.
Directed readings on a topic chosen by the student with the advice of an instructor. May be repeated for additional credit. Consent of the department required for enrollment.

MATH 800. Complex Analysis I. 3 Credits.
Cauchy's theorem and contour integration; the argument principle; maximum modulus principle; Schwarz symmetry principle; analytic continuation; monodromy theorem; applications to the gamma function and Riemann's zeta function; entire and meromorphic functions; conformal mapping; Riemann mapping theorem; univalent functions. Prerequisite: MATH 766 or concurrently with MATH 766.

MATH 802. Set Theory. 3 Credits.
Axiomatic set theory; transfinite induction; regularity and choice; ordinal and cardinal arithmetic; miscellaneous additional topics (e.g., extra axioms such as GCH or MA; infinite combinatorics; large cardinals). Prerequisite: MATH 765 or MATH 791, or concurrent enrollment in MATH 765 or MATH 791, or equivalent evidence of mathematical maturity.

MATH 810. Real Analysis and Measure Theory I. 3 Credits.
Measurable spaces and functions. Measure spaces and integration. Extensions of set functions, outer measures, Lebesgue measure. Signed and complex measures. Differentiation of set functions. Miscellaneous additional topics and applications. Prerequisite: MATH 766.

MATH 820. Introduction to Topology. 3 Credits.
General topology. Set theory; topological spaces; connected sets; continuous functions; generalized convergence; product and quotient spaces; embedding in cubes; metric spaces and metrization; compact spaces; function spaces. Prerequisite: MATH 765.

MATH 821. Algebraic Topology I. 3 Credits.
The fundamental group and covering spaces (including classification); compact surfaces; homology theory, computations (including homotopy invariance) and applications (including Brouwer fixed point theorem); introduction to cohomology theory. Prerequisite: MATH 790 and MATH 791 and MATH 820, or permission of instructor.

MATH 824. Algebraic Combinatorics. 3 Credits.
An introduction to the fundamental structures and methods of modern algebraic combinatorics. Topics include partially ordered sets and lattices, matroids, simplicial complexes, polytopes, hyperplane arrangements, partitions and tableaux, and symmetric functions. Prerequisite: MATH 724 and MATH 791, or permission of the instructor.

MATH 830. Abstract Algebra. 3 Credits.
This is an introductory course covering the basics of module theory over commutative rings. Topics include quotient modules and module homomorphisms; direct sums and free modules; tensor products of modules and exact sequences; projective, injective, and flat modules; direct and inverse limits of modules; the theory of modules over principal ideal domains, and normal forms; graded rings and modules. Prerequisite: MATH 790 and MATH 791.

MATH 831. Abstract Algebra II. 3 Credits.
This course covers foundational topics in commutative algebra not covered in MATH 830. Potential topics include integral extensions, lying over and going-up; normal rings and going-down; Noether normalization, and dimension theory for finitely generated algebras over a field; chain

conditions, and Noetherian and Artinian rings and modules; local rings and Nakayama's Lemma; rings of formal power series; completion and flatness; primary decomposition and associated primes; affine algebraic varieties and Hilbert's Nullstellensatz; the prime spectrum of a ring and the Zariski topology. Prerequisite: MATH 830.

MATH 840. Differentiable Manifolds. 3 Credits.
Multilinear algebra of finite dimensional vector spaces over fields; differentiable structures and tangent and tensor bundles; differentiable mappings and differentials; exterior differential forms; curves and surfaces as differentiable manifolds; affine connections and covariant differentiation; Riemannian manifolds. Prerequisite: MATH 765 and MATH 790.

MATH 850. Differential Equations and Dynamical Systems. 3 Credits.
Discrete and differentiable dynamical systems with an emphasis on the qualitative theory. Topics to be covered include review of linear systems, existence and uniqueness theorems, flows and discrete dynamical systems, linearization (Hartman-Grobman theorem), stable and unstable manifolds, Poincare sections, normal forms, Hamiltonian systems, and an introduction to bifurcation theory and chaos. Prerequisite: MATH 320 and MATH 766, or permission of instructor.

MATH 851. Topics in Dynamical Systems: _____. 3 Credits.
Topics to be covered include complex dynamical systems, perturbation theory, nonlinear analysis of time series, chaotic dynamical systems, and numerical methods as dynamical systems. Topics may vary. Course may be repeated if topic varies. Prerequisite: MATH 850 or permission of instructor.

MATH 865. Stochastic Processes I. 3 Credits.
Markov chains; Markov processes; diffusion processes; stationary processes. Emphasis is placed on applications: random walks; branching theory; Brownian motion; Poisson process; birth and death processes. Prerequisite: MATH 627 and MATH 765.

MATH 866. Stochastic Processes II. 3 Credits.
This is a second course in stochastic processes, focused on stochastic calculus with respect to a large class of semi-martingales and its applications to topics selected from classical analysis (linear PDE), finance, engineering, and statistics. The course will start with basic properties of martingales and random walks and then develop into the core program on Ito's stochastic calculus and stochastic differential equations. These techniques provide useful and important tools and models in many pure and applied areas. Prerequisite: MATH 727 and MATH 865.

MATH 874. Statistical Decision Theory. 3 Credits.
Game theory, admissible decision functions and complete class theorems; Bayes and minimax solutions; sufficiency; invariance; multiple decision problems; sequential decision problems. Prerequisite: MATH 628 and MATH 766.

MATH 881. Topics in Advanced Numerical Linear Algebra: _____. 3 Credits.
Advanced topics in numerical linear algebra including pseudo-spectra, rounding error analysis and perturbation theory, numerical methods for problems with special structure, and numerical methods for large scale problems. Topics may vary. Course may be repeated if topic varies. Prerequisite: MATH 781, MATH 782, MATH 790, or permission of the instructor.

MATH 882. Topics in Advanced Numerical Differential Equations: _____. 3 Credits.
Advanced course in the numerical solution of ordinary and partial differential equations including modern numerical methods and the associated analysis. Topics may vary. Course may be repeated if topic varies. Prerequisite: MATH 781, MATH 782, MATH 783, or permission of the instructor.

MATH 890. Fourier Analysis. 3 Credits.
Introduction to modern techniques in Fourier Analysis in the Euclidean setting with emphasis in the study of functions spaces and operators acting on them. Topics may vary from year to year and include, among others, distribution theory, Sobolev spaces, estimates for fractional integrals and fractional derivatives, wavelets, and some elements of Calderón-Zygmund theory. Applications in other areas of mathematics, in particular partial differential equations and signal analysis, will be presented based on the instructor's and the students' interests. Prerequisite: MATH 810 and MATH 800, or instructor's permission.

MATH 896. Master's Research Component. 1-6 Credits.
Research Component Hours. Graded on a satisfactory progress/limited progress/no progress basis.

MATH 899. Master's Thesis. 1-10 Credits.
Thesis Hours. Graded on a satisfactory progress/limited progress/no progress basis.

MATH 910. Algebraic Curves. 3 Credits.
Algebraic sets, varieties, plane curves, morphisms and rational maps, resolution of singularities, Reimann-Roch theorem. Prerequisite: MATH 790 and MATH 791.

MATH 920. Lie Groups and Lie Algebras. 3 Credits.
General properties of Lie groups, closed subgroups, one-parameter subgroups, homogeneous spaces, Lie bracket, Lie algebras, exponential map, structure of semi-simple Lie algebras, invariant forms, Maurer-Cartan equation, covering groups, spinor groups. Prerequisite: MATH 766 and MATH 790 and MATH 791.

MATH 940. Advanced Probability. 3 Credits.
Probability measures, random variables, distribution functions, characteristic functions, types of convergence, central limit theorem. Laws of large numbers and other limit theorems. Conditional probability, Markov processes, and other topics in the theory of stochastic processes. Prerequisite: MATH 810.

MATH 950. Partial Differential Equations. 3 Credits.
Introduction; equations of mathematical physics; classification of linear equations and systems. Existence and uniqueness problems for elliptic, parabolic, and hyperbolic equations. Eigenvalue problems for elliptic operators; numerical methods. Prerequisite: MATH 766.

MATH 951. Topics in Advanced Partial Differential Equations II: _____. 3 Credits.
The course uses functional analytic techniques to further develop various aspects of the modern framework of linear and nonlinear partial differential equations. Sobolev spaces, distributions and operator theory are used in the treatment of linear second-order elliptic, parabolic, and hyperbolic equations. In particular we discuss the kind of potential, diffusion and wave equations that arise in inhomogeneous media, with an emphasis on the solvability of equations with different initial/boundary conditions. Then, we will survey the theory of semigroup of operators, which is one of the main tools in the study of the long-time behavior of solutions to nonlinear PDE. The theories and applications encountered in this course will create a strong foundation for studying nonlinear equations and nonlinear science in general. Topics may vary. Course may be repeated if topic varies. Prerequisite: MATH 950 or permission of the instructor.

MATH 960. Functional Analysis. 3 Credits.

Topological vector spaces, Banach spaces, basic principles of functional analysis. Weak and weak-topologies, operators and adjoints. Hilbert spaces, elements of spectral theory. Locally convex spaces. Duality and related topics. Applications. Prerequisite: MATH 810 and MATH 820 or concurrent with MATH 820.

MATH 961. Topics in Functional Analysis: _____. 3 Credits.
Continuation of MATH 960. Topics may vary. Course may be repeated if topic varies.

MATH 990. Seminar: _____. 1-10 Credits.

MATH 993. Readings in Mathematics. 1-10 Credits.

MATH 996. Special Topics: _____. 3 Credits.
Advanced courses on special topics; given as need arises. Prerequisite: Variable.

MATH 999. Doctoral Dissertation. 1-10 Credits.
Dissertation Hours. Graded on a satisfactory progress/limited progress/no progress basis.