MATHEMATICS MTH

Department of Mathematics
College of Natural Science

100E Intermediate Algebra Workshop for the Mathematics Enrichment Program
Fall, Spring. 1(0-4) R: Approval of department. C: MTH 1825 concurrently.
Enrichment topics in intermediate algebra for students in the Mathematics Enrichment Program.

101 Quantitative Literacy I
Fall. 3 credits. P: (MTH 1825 or MTH 103) or designated score on Mathematics Placement test
Quantitative literacy including applications to health and risk, science, and the environment.

102 Quantitative Literacy II
Spring. 3 credits. P: (MTH 1825 or MTH 103) or designated score on Mathematics Placement test
Quantitative literacy including applications to finance, economics, and politics.

103 College Algebra
Fall, Spring, Summer. 3(3-0) P: (MTH 1825) or designated score on Mathematics Placement test SA: LBS 117 Not open to students with credit in MTH 116.
Number systems; functions and relations; exponents and logarithms; elementary theory of equations; inequalities; and systems of equations.

103E College Algebra Workshop for the Mathematics Enrichment Program
Fall, Spring. 1(0-4) R: Approval of department. C: MTH 103 concurrently.
Enrichment topics in college algebra for students in the Mathematics Enrichment Program.

110 Finite Mathematics and Elements of College Algebra
Fall, Spring, Summer. 5(5-0) P: (MTH 1825) or designated score on Mathematics Placement test Not open to students with credit in MTH 112.
Functions and graphs. Equations and inequalities. Systems of equations. Matrices. Linear programming. Simplex algorithm. Probability and statistics.

112 Finite Mathematics: Applications of College Algebra
Fall, Spring, Summer. 3(3-0) P: (MTH 103) or designated score on Mathematics Placement test SA: MTH 106 Not open to students with credit in MTH 110.
Combinatorics, probability and statistics, mathematics of finance, geometry, transition matrices, and linear programming. The course emphasizes applications and includes work using spreadsheets.

114 Trigonometry
Fall, Spring, Summer. 3(3-0) P: MTH 103 SA: MTH 104 Not open to students with credit in MTH 116.
Radian and degree measure of angles. Definitions and graphs of trigonometric functions and their inverses. Solving trigonometric equations. Applications including identities, indirect measurement and trigonometric modeling.

116 College Algebra and Trigonometry
Fall, Spring, Summer. 5(5-0) P: (MTH 1825) or designated score on Mathematics Placement test SA: LBS 117 Not open to students with credit in MTH 103.
Functions and graphs. Equations and inequalities. Exponential and logarithmic functions. Trigonometric functions. Systems of equations. Binomial theorem.

124 Survey of Calculus I
Fall, Spring, Summer. 3(3-0) P: (MTH 103 or MTH 116) or designated score on Mathematics Placement test
Study of limits, continuous functions, derivatives, integrals and their applications.

126 Survey of Calculus II
Fall, Spring, Summer. 3(3-0) P: MTH 124 Not open to students with credit in MTH 133 or MTH 153H.
Application of partial derivatives, integrals, optimization of functions of several variables and differential equations.

132 Calculus I
Fall, Spring, Summer. 3(3-0) P: (MTH 103 and MTH 114) or (MTH 116 or designated score on Mathematics Placement test)
Limits, continuous functions, derivatives and their applications. Integrals and the fundamental theorem of calculus.

133 Calculus II
Fall, Spring, Summer. 4(4-0) P: MTH 132 or MTH 152H or LB 118 Not open to students with credit in LB 119 or MTH 153H.
Applications of the integral and methods of integration. Improper integrals. Polar coordinates and parametric curves. Sequences and series. Power series.

152H Honors Calculus I
Fall. 3(3-0) R: Open to students in the Honors College or approval of department. Not open to students with credit in LB 118 or MTH 132.
Limits, continuous functions, derivatives, integrals, fundamental theorem of calculus. Special emphasis on concepts and theory.

153H Honors Calculus II
Fall, Spring. 4(5-0) P: MTH 152H or MTH 132 or LB 118 R: Open to students in the Honors College or approval of department. Not open to students with credit in MTH 133 or LB 119.
The integral. Improper integrals. Polar coordinates and parametric curves. Sequences and series. Power and Taylor series. Special emphasis on concepts and theory.

1825 Intermediate Algebra
Fall, Spring, Summer. 3(3-0)
Properties of real numbers. Factoring. Roots and radicals. First and second degree equations. Linear inequalities. Polynomials. Systems of equations.

201 Elementary Mathematics for Teachers I
Fall, Spring, Summer. 3(3-0) P: (MTH 103 or MTH 110 or MTH 116 or MTH 124 or MTH 132 or MTH 152H or LB 118) or designated score on Mathematics Placement test R: Open to students in the Child Development major or in the Education Major or in the Special Education-Learning Disabilities Major or in the Teacher Certification Internship Year Studies Program.
Mathematics needed for K-8 teaching. Place value and models for arithmetic, mental math, word problems, and algorithms. Factors, primes, proofs, and prealgebra. Fractions, ratios, rates, and percentages. Negative, rational, and real numbers. Special emphasis on the appropriate sequential order for teaching.

202 Elementary Mathematics for Teachers II
Fall, Spring, Summer. 3(3-0) P: MTH 201 R: Open to students in the Education Major or in the Special Education-Learning Disabilities Major or in the Child Development major or in the Teacher Certification Internship Year Studies Program.
A continuation of MTH 201. Geometry, measurement, and elementary data analysis.

234 Multivariable Calculus
Fall, Spring, Summer. 4(4-0) P: MTH 133 or MTH 153H or LB 119
Vectors in space. Functions of several variables and partial differentiation. Multiple integrals. Line and surface integrals. Green's and Stokes's theorems.

235 Differential Equations
Fall, Spring, Summer. 3(4-0) P: MTH 234 or MTH 254H or LB 220 R: Not open to students in the Bachelor of Science in Mathematics or in the Bachelor of Arts in Mathematics or in the Lyman Briggs Mathematics Coordinate Major. Not open to students with credit in MTH 347H or MTH 340.
Separable and exact equations. Linear equations and variation of parameters. Higher order linear equations. Laplace transforms. Systems of first-order linear equations. Introduction to partial differential equations and Fourier series.

254H Honors Multivariable Calculus
Fall, Spring. 4(5-0) P: MTH 153H or MTH 133 or LB 119 R: Open to students in the Honors College or approval of department. Not open to students with credit in MTH 234 or LB 220.
Vectors in space. Functions of several variables and partial differentiation. Multiple integrals. Line and surface integrals. Green's and Stokes's Theorems.

290 Directed Study
Fall, Spring, Summer. 1 to 4 credits. A student may earn a maximum of 6 credits in all enrollments for this course.
Faculty directed study of selected mathematical topics.

299 Transitions
Fall, Spring, Summer. 4 credits. P: MTH 132 or MTH 152H or LB 118 RB: (MTH 133 or concurrently) or (LB 119 or concurrently)
Introduction to mathematical reasoning, basic logic, set theory, integers, natural numbers and induction, basic number theory, real numbers, limits, sequences, series.

301 Foundations of Higher Mathematics
Fall, Spring. 3(3-0) P: (MTH 133 or MTH 153H or LB 119) and MTH 202 R: Open to students in the Mathematics Elementary Teaching Major or in Mathematics-Elementary Disciplinary Teaching Minor or approval of department.
Elementary set theory including permutations, combinations, cardinality theorems, relations, functions and quotient sets. Basic principles of logic and proof techniques. Elementary number theory and abstract algebra.

304 Algebra for Elementary and Middle School Teachers
Fall. 3 credits. Interdepartmental with Teacher Education. Administered by Mathematics. P: (MTH 201 and MTH 202 and MTH 301) and completion of Tier I writing requirement R: Open to undergraduate students in the College of Education or in the Department of Teacher Education. Approval of department.
Algebra needed for understanding connections between topics of algebra and the mathematics taught in elementary and middle school.

305 Functions and Calculus for Elementary and Middle School Teachers (W)
Spring. 3(3-0) Interdepartmental with Teacher Education. Administered by Mathematics. P: (MTH 304) and completion of Tier I writing requirement
Functions and calculus needed for understanding connections between topics of calculus and the mathematics taught in middle school.

309 Linear Algebra I
Fall, Spring, Summer. 3(3-0) P: ((MTH 133 or MTH 153H or LB 119) and completion of Tier I writing requirement) and (MTH 299 or approval of department) Not open to students with credit in MTH 317H.
Matrices, systems of linear equations, vector spaces, linear transformations, inner products and orthogonal spaces, eigenvalues and eigenvectors, and applications to geometry. A writing course with emphasis on proofs.

310 Abstract Algebra I and Number Theory
Fall, Spring, Summer. 3(3-0) P: ((MTH 299 or MTH 317H) or approval of department) and completion of Tier I writing requirement Not open to students with credit in MTH 418H.
Structure of the integers, congruences, rings, ring homomorphisms, ideals, quotient rings. A writing course with an emphasis on proofs.

314 Matrix Algebra with Applications
Fall, Spring, Summer. 3(3-0) P: MTH 133 or MTH 153H or LB 119 R: Not open to students in the Actuarial Science Major or in the Bachelor of Arts in Computational Mathematics or in the Bachelor of Science in Computational Mathematics or in the Mathematics Minor or in the Bachelor of Science in Mathematics or in the Bachelor of Arts in Mathematics or in the Bachelor of Science in Mathematics, Advanced or in the Bachelor of Arts in Mathematics, Advanced or in the Mathematics-Elementary Disciplinary Teaching Minor or in Mathematics-Secondary Disciplinary Teaching Minor.
Problem-solving and applications in matrix algebra for scientists and engineers. Vectors, matrices, linear transformations, inner products, dimension, eigenvalues and eigenvectors. Applications to systems of equations and to geometry.

317H Honors Linear Algebra
Fall, Spring. 4(5-0) P: MTH 133 or MTH 153H or LB 119 R: Open to students in the Honors College or approval of department. Not open to students with credit in MTH 309.
Systems of equations, matrix algebra, vector spaces, linear transformations, geometry of R^n, eigenvalues, eigenvectors, diagonalization, inner products. Emphasis on mathematical reasoning, proofs, and concepts.

320 Analysis I
Fall, Spring, Summer. 3(3-0) P: (MTH 133 or MTH 153H or LB 119) and (MTH 299 or MTH 317H or approval of department) Not open to students with credit in MTH 327H.
Convergence of sequences and series. Upper and lower limits, completeness, limits and continuity. Derivatives. Uniform convergence.

327H Honors Introduction to Analysis
Fall, Spring. 3(3-0) P: MTH 317H R: Approval of department.
Emphasis on foundations and metric topology. Convergence of sequence and series, continuity of functions. Differentiation and integration in one dimension.

330 Higher Geometry
Fall, Spring, Summer. 3(3-0) P: MTH 301 or MTH 299 or MTH 317H
Topics in transformations: isometries, similarities, inversion. Advanced Euclidean geometry: theorems of Menelaus, Ceva, and Desargues. Cross ratio, harmonic points, analytic, metric, and vector methods, and convexity.

340 Ordinary Differential Equations I
Fall, Spring, Summer. 3(3-0) P: (MTH 309 or MTH 317H) and (MTH 133 or MTH 153H or LB 119) Not open to students with credit in MTH 347H.
Techniques for solving differential equations, existence and uniqueness theorems, qualitative theory, Fourier series and applications.

347H Honors Ordinary Differential Equations
Spring. 3(3-0) P: (MTH 309 or MTH 317H) and (MTH 133 or MTH 153H or LB 119) R: Approval of department.
Separable and exact equations, linear equations and variation of parameters, higher order linear equations, Laplace Transforms, first-order linear systems, classification of singularities, nonlinear systems, partial differential equations and Fourier Series, existence and uniqueness theorems. Emphasis on theory.

360 Theory of Mathematical Interest
Fall, Spring. 3(3-0) P: (MTH 133 or concurrently) or (MTH 153H or concurrently) or (LB 119 or concurrently) or approval of department
Measurement of interest rates, basic problems in interest theory, basic annuities, continuous and varying annuities, yield rates, amortization, bonds and other securities, practical applications, and stochastic approaches to interest.

361 Financial Mathematics for Actuaries I
Fall, Spring. 3(3-0) P: MTH 360 C: STT 441 concurrently.
Introduction to the mathematics of financial derivatives. Options, forwards, futures, swaps, investment and hedging strategies.

396 Capstone in Mathematics for Secondary Education (W)
Spring. 3(3-0) P: (MTH 309 or MTH 317H or approval of department) and (MTH 310 or MTH 418H or approval of department) and (MTH 320 or MTH 327H or approval of department) and Completion of Tier I Writing Requirement R: Approval of department. Not open to students with credit in MTH 496.
A capstone course for secondary education math majors. High school mathematics from an advanced viewpoint.

411 Abstract Algebra II
Fall, Spring. 3(3-0) P: MTH 310 Not open to students with credit in MTH 419H.
Continuation of MTH 310. Permutation groups, groups of transformations, normal subgroups, homomorphism theorems, modules. Principal ideal rings, unique factorization domains, noncommutative rings, rings of fractions, ideals.

414 Linear Algebra II
Fall. 3(3-0) P: MTH 309 or MTH 317H Not open to students with credit in MTH 415.
Linear transformations on finite dimensional vector spaces. Invariant subspaces, rank, eigenvalues and eigenvectors. Canonical forms. Bilinear and multilinear forms.

415 Applied Linear Algebra
Fall, Spring, Summer. 3(3-0) P: (MTH 235 or MTH 340 or MTH 347H) and (MTH 309 or MTH 314 or MTH 317H) Not open to students with credit in MTH 414.
Matrices and linear algebra. General linear systems of equations. Least squares minimization techniques. Eigenvalues and eigenvectors, spectral decompositions, and exponentials.

416 Introduction to Algebraic Coding
Fall. 3(3-0) P: MTH 309 or MTH 317H RB: MTH 310
Concepts and techniques of abstract algebra applied to the design of communication systems for use in imperfect circumstances. Theory of codes designed by algebraic means.

417 Topics in Number Theory
Spring of even years. 3(3-0) P: (MTH 310 or MTH 418H) and ((MTH 411 or concurrently) or (MTH 419H or concurrently))
Congruences of higher degree, primitive roots and quadratic reciprocity. Number-theoretic functions, algebraic numbers. Dirichlet Series, p-order expansion, continued fractions.

418H Honors Algebra I
Fall. 3(3-0) P: MTH 317H or MTH 299 RB: Linear Algebra R: Approval of department.
Theory of groups, Sylow theory, the structure of finite Abelian groups, ring theory, ideals, homomorphisms, and polynomial rings.

419H Honors Algebra II
Spring. 3(3-0) P: MTH 418H R: Approval of department.
Algebraic field extensions, Galois theory. Classification of finite fields. Fundamental Theorem of Algebra.

421 Analysis II
Fall, Spring. 3(3-0) P: (MTH 320 or MTH 327H) and (MTH 234 or MTH 254H or LB 220) Not open to students with credit in MTH 429H.
Continuation of MTH 320. Riemann integral. Metric spaces. Differentiation in higher dimensions. Inverse and implicit function theorems.

425 Complex Analysis
Fall, Spring. 3(3-0) P: MTH 320 Not open to students with credit in MTH 428h.
Analytic functions of a complex variable, Cauchy integral theorem, conformal maps, bilinear transformation, harmonic functions. Classification of singularities, residues, conformal mappings.

428H Honors Complex Analysis
Fall. 3(3-0) P: MTH 327H R: Approval of department.
Analytic functions of a complex variable, line integrals and harmonic functions, Cauchy's theorem and integral formula, power series, Laurent series, isolated singularities, residue calculus, Rouche's theorem, automorphisms of the disk, the Riemann mapping theorem.

429H Honors Real Analysis
Spring. 3(3-0) P: MTH 327H and (MTH 234 or MTH 254H or LB 220) R: Approval of department.
Continuation of MTH 327H. Convergence of sequences and series of functions, differentiation and integration in higher dimensional settings. Inverse and implicit function theorems.

432 Axiomatic Geometry
Spring. 3(3-0) P: MTH 299 or MTH 317H
Axiomatic systems and finite geometries: axioms of Euclidean and hyperbolic geometry, the Poincare model, independence of the parallel postulate. Classical constructions and the impossibility of angle trisection.

441 Ordinary Differential Equations II
Fall. 3(3-0) P: (MTH 235 or MTH 340 or MTH 347H) and (MTH 309 or MTH 317H or MTH 314 or MTH 415)
Existence and uniqueness theorems; Linearization; Local and global stability; Saddle-node, Hopf and heteroclinic bifurcations; Hamiltonian and gradient system; The Poincare map; The Poincare-Bendixson theorem and limit cycles; Selected applications.

442 Partial Differential Equations
Spring. 3(3-0) P: MTH 235 or MTH 340 or MTH 347H
Classification of second order partial differential equations. Boundary and initial value problems for heat, Laplace, and wave equations in dimensions 1, 2 and 3. Variational methods and maximum principles. Separation of variables, Fourier series, Sturm-Liouville theory. Greens functions.

451 Numerical Analysis I
Fall. 3(3-0) P: (CSE 131 or CSE 231) and (CSE 131 or CSE 231) and (MTH 235 or MTH 340 or MTH 347H) SA: MTH 351
Numerical solution of linear and nonlinear algebraic equations and eigenvalue problems. Curve fitting. Interpolation theory. Numerical integration, differentiation, and solution of differential equations. Algorithms implementation with a programming language like Fortran, C/C++ or MATLAB.

452 Numerical Analysis II
Spring. 3(3-0) P: MTH 451
Iterative methods for solving linear systems, approximation theory, approximating eigenvalues, solutions of systems of nonlinear equations, boundary-value problems for ordinary differential equations, numerical methods for partial differential equations.

455 Actuarial Models I
Fall. 3(3-0) Interdepartmental with Statistics and Probability. Administered by Statistics and Probability. P: STT 441 and MTH 360
Stochastic models used in insurance. Survival distributions, life insurance, life annuities, benefit premiums, benefit reserves, and analysis of benefit reserves.

456 Actuarial Models II
Spring. 3(3-0) Interdepartmental with Statistics and Probability. Administered by Statistics and Probability. P: STT 455
Continuation of STT 455. Benefit reserves. Multiple life functions. Multiple decrement models and their applications. Elements of stochastic processes for actuaries including Markov chains and Poisson processes

457 Introduction to Financial Mathematics
Spring. 3(3-0) P: (MTH 309) and (MTH 235 or MTH 340 or MTH 347H) and (STT 441 or STT 351)
Mathematical overview of basic financial instruments. A unified partial differential equation approach to model derivative securities. Partial differential equations in financial mathematics, Black-Scholes equation. Numerical methods for valuing derivatives.

458 Financial Mathematics for Actuaries II
Fall. 3(3-0) Interdepartmental with Statistics and Probability. Administered by Mathematics. P: MTH 361 and STT 441 RB: MTH 235 or MTH 340 or MTH 347H
Evaluate and construct interest rate models. Rational valuation of derivative securities using put-call parity and calculation of European and American options. Risk management techniques using the method of delta-hedging.

459 Construction and Evaluation of Actuarial Models
Spring. 3(3-0) Interdepartmental with Statistics and Probability. Administered by Statistics and Probability. P: STT 442
Severity, frequency, and aggregate models. Construction of empirical models. Parametric statistical methods. Credibility analysis. Simulation methods.

461 Metric and Topological Spaces
Fall. 3(3-0) P: MTH 320 or MTH 327H
Set theory, metric spaces, topological spaces, maps, product and quotient topologies. Connected and compact spaces, separation axioms, pointwise and uniform convergence.

481 Discrete Mathematics I
Fall, Spring. 3(3-0) P: MTH 309
Binomial and multinomial theorems. Graphs and digraphs, graph coloring. Generating functions, asymptotic analysis, trees. Representing graphs in computers.

482 Discrete Mathematics II
Spring. 3(3-0) P: MTH 481 RB: MTH 310
Recurrence and generating functions, Ramsey theory. Block designs, Latin squares, Eulerian and Hamiltonian paths. Minimum spanning trees, network flows.

490 Directed Studies
Fall, Spring, Summer. 1 to 4 credits. A student may earn a maximum of 9 credits in all enrollments for this course. R: Approval of department.
Faculty directed study in a selected mathematical topic.

491A Actuarial Internship
Summer. 3(3-0) P: Completion of Tier I Writing Requirement RB: STT 441 and FI 311 and MTH 360 R: Approval of department.
Survey of typical actuarial type projects at an actuarial firm such as data analysis, risk analysis, interest rate models, life insurance, benefit programming, analysis of benefit reserves.

491B Teamwork Experience
Fall, Spring. 1(1-0) R: Approval of department.
A field type experience to develop communication skills working in a group setting on multi-faceted projects.

492H Undergraduate Thesis (W)
Fall, Spring, Summer. 3 credits. A student may earn a maximum of 12 credits in all enrollments for this course. P: Completion of Tier I Writing Requirement R: Approval of department; application required.
Undergraduate thesis on an advanced-level topic in mathematics.

496 Capstone in Mathematics (W)
Fall, Spring. 3(3-0) P: (MTH 309 or MTH 317H or approval of department) and (MTH 310 or MTH 418H or approval of department) and (MTH 320 or MTH 327H or approval of department) and Completion of Tier I Writing Requirement R: Approval of department.
A capstone course integrating several areas of mathematics.

810 Error-Correcting Codes
Spring. 3(3-0) RB: MTH 411 or MTH 414 or MTH 415
Block codes, maximum likelihood decoding, Shannon's theorem. Generalized Reed-Solomon codes, modification of codes, subfield codes. Alterant and Goppa codes, cyclic codes and BCH codes.

818 Algebra I
Fall. 3(3-0) RB: MTH 411
Group theory: Sylow theory, permutation groups, Jordon-Hoelder theory, Abelian groups, free groups. Ring theory: algebra of ideals, unique factorization, polynomial rings, finitely generated modules over PIDs.

819 Algebra II
Spring. 3(3-0) RB: MTH 818
Modules and vector spaces, projectives modules, tensor algebra. Fields and Galois groups, algebraic and transcendental numbers, non-commutative rings. The Jacobson radical, the structure of semisimple rings with the descending chain condition.

828 Real Analysis I
Fall. 3(3-0) RB: MTH 421 and MTH 461
Lebesgue measure on real line, general measure theory. Convergence theorems, Lusin's theorem, Egorov's theorem, Lp-spaces, Fubini's theorem. Functions of bounded variation, absolutely continuous functions, Lebesgue differentiation theorem.

829 Complex Analysis I
Spring. 3(3-0) RB: MTH 421 and MTH 425
Cauchy theorem, identity principle, Liouville's theorem, maximum modulus theorem. Cauchy formula, residue theorem, Rouche's theorem. Casorati-Weierstrass theorem, Arzela-Ascoli theorem. Conformal mapping, Schwarz lemma, Riemann mapping theorem.

840 Chaos and Dynamical Systems
Spring. 3(3-0) RB: (MTH 441 and MTH 320 and MTH 414) and some experience with mathematical software such as Mathematica or Matlab.
Chaotic or random motions in differential and difference equations.

841 Boundary Value Problems I
Fall. 3(3-0) RB: MTH 414 and MTH 421
Methods for solving boundary and initial value problems for ordinary and partial differential equations.

842 Boundary Value Problems II
Spring. 3(3-0) RB: MTH 841
Continuation of MTH 841.

843 Survey of Industrial Mathematics
Fall. 3(3-0) RB: ((MTH 414 or MTH 415) or Some familiarity with mathematical software such as Mathematica, Matlab, etc.) and (MTH 421 and MTH 442) R: Open only to master's students in the Industrial Mathematics major or approval of department.
Fundamentals of mathematical modeling in government and industry, including modes of industrial communication.

844 Projects in Industrial Mathematics
Spring. 3(3-0) RB: ((MTH 414 or MTH 415) or some familiarity with mathematical software such as Mathematica or Matlab.) and (MTH 421 and MTH 442 and MTH 843) R: Open only to master's students in the Industrial Mathematics major or approval of department.
Participation as a member of a 3-4 person team on a significant industrial problem, with participation of an industrial liaison, including project report generation and reporting.

847 Partial Differential Equations I
Fall. 3(3-0) RB: Equivalent of MTH 414 R: Open to doctoral students in the College of Natural Science.
Basic theory and techniques for general first-order equations, Laplace's equation, the heat equation and wave equations, with certain generalizations to the second-order linear equations of elliptic, parabolic and hyperbolic types.

848 Ordinary Differential Equations
Fall. 3(3-0) RB: MTH 414 and MTH 421
Existence and uniqueness theorems. Theory of linear differential equations. Floquet theory. Stability theory and Poincare-Bendixson theory. Green's functions and boundary value problems.

849 Partial Differential Equations
Spring. 3(3-0) RB: MTH 414 and MTH 421
Cauchy-Kowalewski theorem. Characteristics. Initial-boundary value problems for parabolic and hyperbolic equations. Energy methods, boundary value problems for elliptic equations, potential theory. Green's function, maximum principles, Schauder's method.

850 Numerical Analysis I
Fall. 3(3-0) RB: MTH 414 and MTH 421
Convergence and error analysis of numerical methods in applied mathematics.

851 Numerical Analysis II
Fall. 3(3-0) RB: MTH 850 and MTH 852
Spectral methods for boundary value problems, eigenvalue problems, and time-dependent problems. Trigonometric and Chebyshev polynomials. Fast Fourier transforms.

852 Numerical Methods for Ordinary Differential Equations
Spring. 3(3-0) RB: MTH 850
Linear multi-step methods and single step nonlinear methods for initial value problems. Consistency, stability and convergence. Finite difference, finite element, shooting methods for boundary value problems.

864 Geometric Topology
Spring. 3(3-0) RB: MTH 421 SA: MTH 464
Topology of surfaces and higher dimensional manifolds, studied from combinatorial, algebraic or differential viewpoints.

868 Geometry and Topology I
Fall. 3(3-0) RB: (MTH 411 and MTH 421) or approval of department.
Fundamental group and covering spaces, van Kampen's theorem. Homology theory, Differentiable manifolds, vector bundles, transversality, calculus on manifolds. Differential forms, tensor bundles, deRham theorem, Frobenius theorem.

869 Geometry and Topology II
Spring. 3(3-0) RB: MTH 868
Continuation of MTH 868.

879 Teaching College Mathematics
Fall of even years. 3(3-0) A student may earn a maximum of 6 credits in all enrollments for this course. Interdepartmental with Counseling, Educational Psychology and Special Education and Mathematics Education and Teacher Education. Administered by Mathematics Education. RB: Past or concurrent mathematics teaching experience. SA: SME 879
Curriculum materials, case studies, approaches to teaching and student learning of particular mathematics topics.

880 Combinatorics
Fall. 3(3-0) RB: MTH 411 or MTH 482
Enumerative combinatorics, recurrence relations, generating functions, asymptotics, applications to graphs, partially ordered sets, generalized Moebius inversions, combinatorial algorithms.

881 Graph Theory
Spring. 3(3-0) RB: MTH 880
Graph theory, connectivity, algebraic and topological methods. Networks, graph algorithms, Hamiltonian and Eulerian graphs, extremal graph theory, random graphs.

890 Readings in Mathematics
Fall, Spring, Summer. 1 to 6 credits. A student may earn a maximum of 24 credits in all enrollments for this course. R: Approval of department.
Individualized study for Master's level students.

910 Commutative Algebra
Fall of odd years. 3(3-0) RB: MTH 819
Noetherian rings and modules, localization and tensor products, primary decomposition, Krull dimensions, graded rings and modules, Hilbert's Nullstellensatz, integral extensions, discrete valuation rings, Dedekind domains.

912 Group Theory I
Fall of even years. 3(3-0) RB: MTH 819
Permutation groups, solvable and nilpotent groups, simple groups. Representation and character theory. Extension theory and cohomology groups.

913 Group Theory II
Spring of odd years. 3(3-0) RB: MTH 912
Groups of Lie type, linear groups, locally finite groups, free groups and free products, the subgroup theorems.

914 Lie Groups and Algebras
Fall of odd years. 3(3-0) RB: MTH 819
Nilpotent and semisimple algebras, the ad joint representation, root spaces, Weyl groups, Dynkin diagrams, classification of simple algebras.

916 Introduction to Algebraic Geometry I
Fall of even years. 3(3-0) RB: MTH 818 and MTH 819
Affine and projective algebraic varieties and their properties. Morphisms and singularities. Schemes and coherent sheaves. Sheaf cohomology and other related topics.

917 Introduction to Algebraic Geometry II
Spring of odd years. 3(3-0) RB: MTH 916
Continuation of MTH 916.

918 Number Theory I
Fall of even years. 3(3-0) P: MTH 819 or approval of department
Number fields and algebraic integers, prime ideals and factorization, cyclotomic fields, the class group, the Dirichlet unit theorem, different, discriminant, decomposition and inertia groups, local fields.

919 Number Theory II
Spring of odd years. 3(3-0) P: MTH 918 or approval of department
Topics from: class field theory, zeta and L-functions, modular forms, theory of elliptic curves, diophantine approximation, diophantine geometry.

920 Functional Analysis
Spring. 3(3-0) RB: MTH 828 R: Open to graduate students in the College of Natural Science or approval of department.
Hilbert spaces, Banach spaces and locally convex vector spaces. Topics include Riesz representation theorem, Parseval's identity, Riesz-Fisher theorem, Fourier series operators, Hahn-Banach theorem, open mapping and closed graph theorems, Banach-Steinhaus theorem, duality theory for locally convex spaces, convexity, Krein-Milman theorem, theory of distributions, compact operators.

921 Operator Theory
Fall of even years. 3(3-0) RB: MTH 829 and MTH 920 R: Open to doctoral students in the College of Natural Science or approval of department.
Introduction to operator and spectral theory. Topics include Banach algebras, bounded and unbounded operators on Banach spaces, spectral theory for normal operators on a Hilbert space, C*-algebras, Schatten - von Neumann classes, the theory of Fredholm operators, semigroup theory.

922 Harmonic Analysis
Fall of odd years. 3(3-0) RB: MTH 829 and MTH 920
Fourier series, mean and pointwise convergence, conjugate functions, Fourier transform, Plancherel theorem, Paley-Wiener theorem, interpolation of operators, Hausdorff-Young thoerem.

925 Random Variables and Stochastic Processes
Fall. 3(3-0) R: Open to doctoral students in the College of Natural Science or approval of department.
Introduction to measure-theoretic probability theory. Topics include infinite product spaces, Kolomogorov extension theorem, Borel Cantelli Lemma, law of large numbers, central limit theorem, conditioning, filtrations, martingales, Markov chains, Wiener process.

928 Real Analysis II
Spring of odd years. 3(3-0) RB: MTH 828 R: Open to doctoral students in the College of Natural Science or approval of department.
Continuation of MTH 828. Topics include Borel measures on locally compact spaces, complex measures, differentiable transformations and changes of variables in Rn.

929 Complex Analysis II
Spring of even years. 3(3-0) RB: MTH 828 and MTH 829 R: Open to doctoral students in the College of Natural Science or approval of department.
Continuation of MTH 829. Topics include Phragmen-Lindelof method, Analytic continuation and Riemann surfaces, Hadamard's theorem, Runge's theorem, Weierstrass factorization theorem, Mittag-Leffler theorem, Picard's theorem, Hp-spaces, Blaschke products.

930 Riemannian Geometry I
Fall of even years. 3(3-0) RB: MTH 869
Riemannian metrics, connections, curvature, geodesics. First and second variation, Jacobi fields, conjugate points. Rauch comparison theorems, Hodge theorem, Bochner technique, spinors. Further topics on curvature or submanifold theory.

931 Riemannian Geometry II
Spring of odd years. 3(3-0) RB: MTH 930
Continuation of MTH 930.

935 Complex Manifolds I
Fall of odd years. 3(3-0) RB: MTH 829 and MTH 869
Riemann surfaces, Serre duality, Riemann-Roch theorem. Weierstrass points, Abel's theorem, Plucker formulas. Hermitian metrics, connections, curvature, Hodge theorem. Kaehler metrics, Kodaira vanishing theorem, Chern classes.

936 Complex Manifolds II
Spring of even years. 3(3-0) RB: MTH 935
Continuation of MTH 935.

940 Topics in Partial Differential Equations for Applied Math
Fall of odd years. 3(3-0) RB: MTH 828 R: Open to doctoral students in the College of Natural Science or approval of department.
Partial differential equation techniques for applied mathematics, including, bifurcation theory, partial differential equations as dynamical systems, boundary layers, asymptotic analysis, matched asymptotic and singular perturbations, and homogenization.

941 Linear and Nonlinear Parabolic Equations
Spring of even years. 3(3-0) RB: MTH 940 R: Open to doctoral students in the College of Natural Science or approval of department.
Evolution equations with a comparison principle, including parabolic equations and Hamilton-Jacobi-Bellman equations, with an emphasis on existence and uniqueness of both classical and weak solutions. Linear and nonlinear cases, including quasi-linear parabolic equations related to geometric flows.

942 Regularity for Second Order Elliptic Equations
Fall of even years. 3(3-0) RB: MTH 848 and MTH 849 R: Open to doctoral students in the College of Natural Science or approval of department.
Review of classical regularity results, such as Schauder theory and L-p theory. Elliptic equations with coefficients of low regularity (bounded and measurable) and nonlinear elliptic equations. The Harnack inequality and Holder regularity in the context of both weak solutions of divergence form equations and viscosity solutions of equations in non-divergence form. Higher regularity and applications to minimization problems.

943 Hyperbolic and Dispersive Equations
Spring of odd years. 3(3-0) RB: MTH 942 R: Open to doctoral students in the College of Natural Science. Approval of department.
Classical and modern techniques for higher dimensional hyperbolic and dispersive partial differential equations. Space-time integral estimates, including the classical Strichartz estimate for Schrodinger, Klein-Gordon, and Wave equations, and modern (multi)linear estimates using Fourier, physical-space, and microlocal techniques.

950 Numerical Methods for Partial Differential Equations I
Spring of odd years. 3(3-0) RB: MTH 852
Finite difference methods for ordinary and partial differential equations.

951 Numerical Methods for Partial Differential Equations II
Spring of even years. 3(3-0)
Finite element methods for ordinary and partial differential equations.

960 Algebraic Topology I
Fall. 3(3-0) RB: MTH 869
Cohomology, products, duality, basic homotopy theory, bundles, obstruction theory, spectral sequences, characteristic classes, and other related topics.

961 Algebraic Topology II
Spring. 3(3-0) RB: MTH 960
Continuation of MTH 960.

970 Dynamics I
Fall. 3(3-0) P: (MTH 868 or concurrently) and MTH 869 or approval of department R: Open to doctoral students in the College of Natural Science or approval of department.
Flows and diffeomorphisms, examples, topological and smooth conjugacy, recurrence and limit sets, circle diffeomorphisms, symbolic spaces and expanding maps, structural stability of expanding maps, Perron-Frobenius theorem and discrete Markov processes, topological entropy and volume growth, zeta function, homological growth, linearization, bifurcation theory.

971 Dynamics II
Spring. 3(3-0) P: (MTH 868 or concurrently) and (MTH 869 or concurrently) R: Open to doctoral students in the College of Natural Science or approval of department.
Hyperbolic theory, Anosov systems, invariant manifold theory, geodesic flows on Riemannian manifolds, structural stability theorems, generic properties, horseshoe diffeomorphisms, basic theory of Hamiltonian systems on manifolds, variational principles, Lagrangian and Hamiltonian mechanics, Poisson brackets. Introduction to completely integrable systems.

988 Representation Theory I
Fall of odd years. 3(3-0) P: MTH 819 or approval of department
Representations of finite groups, unitary representations, tensor products and character tables, further theory (Frobenius-Schur indicator, Burnside's theorem, Mackey formula, Frobenius reciprocity), representations of GL(2; Fq), representations of symmetric groups (Young diagrams, Schur-Weyl duality), fundamental theorem of invariant theory, introduction to representations of compact groups

989 Representation Theory II
Spring of even years. 3(3-0) P: MTH 988 or approval of department
Basic objects and notions of representation theory: associative algebras, algebras defined by generators and relations, group algebras, quivers and path algebras, basic general results of representation theory, representations of finite dimensional algebras and semi simple algebras, extensions of representations, representations of quivers.

990 Reading in Mathematics
Fall, Spring, Summer. 1 to 3 credits. A student may earn a maximum of 9 credits in all enrollments for this course. R: Approval of department.
Individualized study for doctoral level students.

991 Special Topics in Algebra
Fall, Spring. 3 to 6 credits. A student may earn a maximum of 18 credits in all enrollments for this course. R: Approval of department.
Advanced topics in algebra.

992 Special Topics in Analysis
Fall, Spring. 3 to 6 credits. A student may earn a maximum of 18 credits in all enrollments for this course. R: Approval of department.
Advanced topics in analysis.

993 Special Topics in Geometry
Fall, Spring. 3 to 6 credits. A student may earn a maximum of 18 credits in all enrollments for this course. R: Approval of department.
Advanced topics in geometry.

994 Special Topics in Applied Mathematics
Fall, Spring. 3 to 6 credits. A student may earn a maximum of 24 credits in all enrollments for this course. R: Approval of department.
Advanced topics in applied mathematics.

995 Special Topics in Numerical Analysis and Operations Research
Fall, Spring. 3 to 6 credits. A student may earn a maximum of 18 credits in all enrollments for this course. R: Approval of department.
Advanced topics in numerical analysis or operations research.

996 Special Topics in Topology
Fall, Spring. 3 to 6 credits. A student may earn a maximum of 18 credits in all enrollments for this course. R: Approval of department.
Advanced topics in topology.

999 Doctoral Dissertation Research
Fall, Spring, Summer. 1 to 24 credits. A student may earn a maximum of 36 credits in all enrollments for this course. R: Approval of department.
Doctoral dissertation research.