

# Mathematics (MATH)

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## **MATH 098. Intermediate Algebra. 3 Credits.**

Properties of the real number system, factoring, linear and quadratic equations, functions, polynomial and rational expressions, inequalities, systems of equations, exponents, and radicals. Offered through Continuing Education. Special fee required. Does not satisfy any requirements for graduation. A grade of C or higher is required in this course to be eligible to take MATH 103 or MATH 104.

## **MATH 103. College Algebra. 3 Credits.**

Relations and functions, equations and inequalities, complex numbers; polynomial, rational, exponential and logarithmic functions; systems of equations, and matrices. Prereq: MATH 98 with a grade of C or higher or placement.

## **MATH 104. Finite Mathematics. 3 Credits.**

Systems of linear equations and inequalities, matrices, linear programming, mathematics of finance, elementary probability and descriptive statistics. Prereq: MATH 98 with a grade of C or higher or placement.

## **MATH 105. Trigonometry. 3 Credits.**

Angle measure, trigonometric and inverse trigonometric functions, trigonometric identities and equations, polar coordinates and applications. Prereq: MATH 103 or placement. Credit awarded only for MATH 105 or MATH 107, not both.

## **MATH 107. Precalculus. 4 Credits.**

Equations and inequalities; polynomial, rational, exponential, logarithmic and trigonometric functions; inverse trigonometric functions; algebraic and trigonometric methods commonly needed in calculus. An expedited, combined offering of MATH 103 and MATH 105. Prereq: Placement into Math 103 and completion of the College Algebra module in eight weeks. Credit awarded only for MATH 105 or MATH 107, not both.

## **MATH 128. Introduction to Linear Algebra. 1 Credit.**

Systems of linear equations, row operations, echelon form, matrix operations, inverses, and determinants. Prereq: MATH 105 or MATH 107. Credit awarded only for MATH 128 or MATH 129, not both.

## **MATH 129. Basic Linear Algebra. 3 Credits.**

Systems of linear equations, matrices, determinants, vector spaces, lines and planes in space, linear transformations, eigenvalues and eigenvectors. Credit awarded only for MATH 128 or MATH 129, not both. Prereq: MATH 105 or MATH 107.

## **MATH 144. Mathematics for Business. 4 Credits.**

Mathematics of finance, linear programming and its applications in business, limits, continuity, derivatives, implicit and logarithmic differentiation, higher order derivatives, optimization and extrema, partial differentiation, extreme values of functions of two variables. Prereq: MATH 103, MATH 107 or placement exam. Credit awarded only for MATH 144 or MATH 146, not both.

## **MATH 146. Applied Calculus I. 4 Credits.**

Limits, derivatives, integrals, exponential and logarithmic functions and applications. Prereq: MATH 103, MATH 107, or placement. Credit awarded only for MATH 144 or MATH 146, not both.

## **MATH 147. Applied Calculus II. 4 Credits.**

Definite integrals, trigonometry, introduction to differential equations, infinite sequences and series, probability and applications. Prereq: MATH 146.

## **MATH 165. Calculus I. 4 Credits.**

Limits, continuity, differentiation, Mean Value Theorem, integration, Fundamental Theorem of Calculus and applications. Prereq: MATH 105 or MATH 107 or placement.

## **MATH 166. Calculus II. 4 Credits.**

Applications and techniques of integration; polar equations; parametric equation; sequences and series, power series. Prereq: MATH 165.

## **MATH 194. Individual Study. 1-5 Credits.**

## **MATH 196. Field Experience. 1-15 Credits.**

## **MATH 199. Special Topics. 1-5 Credits.**

## **MATH 259. Multivariate Calculus. 3 Credits.**

Functions of several variables, vectors in two and three variables, partial derivatives, surfaces and gradients, tangent planes, differentials, chain rule, optimization, space curves, and multiple integrals. Prereq: MATH 166. Credit awarded only for MATH 259 or MATH 265, not both.

## **MATH 265. Calculus III. 4 Credits.**

Multivariate and vector calculus including partial derivatives, multiple integration, applications, line and surface integrals, Green's Theorem, Stoke's Theorem, and Divergence Theorem. Prereq: MATH 166. Credit awarded only for MATH 259 or MATH 265, not both.

## **MATH 266. Introduction to Differential Equations. 3 Credits.**

Solution of elementary differential equations by elementary techniques. Laplace transforms, systems of equations, matrix methods, numerical techniques, and applications. Prereq: MATH 259 or MATH 265. Coreq: MATH 128, MATH 129, or MATH 329.

**MATH 270. Introduction to Abstract Mathematics. 3 Credits.**

Sets, symbolic logic, propositions, quantifiers, methods of proof, relations and functions, equivalence relations, math induction and its equivalents, infinite sets, cardinal numbers, number systems. Prereq: MATH 166.

**MATH 291. Seminar. 1-3 Credits.****MATH 294. Individual Study. 1-5 Credits.****MATH 299. Special Topics. 1-5 Credits.****MATH 329. Intermediate Linear Algebra. 3 Credits.**

Vector spaces over real and complex numbers, matrices, determinants, linear transformations, eigenvalues and eigenvectors, Cayley-Hamilton Theorem, inner product spaces, selected topics and applications. Prereq: MATH 129 and MATH 165.

**MATH 346. Metric Space Topology. 3 Credits.**

Various metrics on Euclidean spaces, metric spaces, open and closed sets, limit points and convergence, Bolzano Weierstrass Theorem, (uniformly) continuous functions, connected spaces, compact spaces and the Heine Borel Theorem, sequence of functions. Prereq: MATH 270.

**MATH 374. Special Problems In Mathematics. 1 Credit.**

Diverse and challenging mathematical problems are considered with the intent of honing students' problem solving and proof writing skills. Pass/Fail only. Prereq: MATH 270.

**MATH 376. Actuarial Exam Study. 1 Credit.**

Selected material from calculus, linear algebra, numerical analysis, and other areas that appear on national actuarial exams. May be repeated for credit. Pass/Fail only. Prereq: MATH 266 and MATH 429.

**MATH 379. Global Seminar. 1-6 Credits.**

NDSU instructed experience or field study in a foreign country. Conducted in English for residence credit. Pre-requisite: Prior approval by International Student and Study Abroad Services and major department. May be repeated. Standard Grading.

**MATH 391. Seminar. 1-3 Credits.****MATH 392. Global Practicum: Study Abroad. 1-15 Credits.**

Pre-Arranged study at accredited foreign institutions (study abroad), domestic institutions (National Student Exchange) or on approved study abroad programs. Pre-requisite: Sophomore standing and prior approval by International Student and Study Abroad Services and major department. Graded 'P' or 'F' (Undergraduate), or 'S' or 'U' (Graduate).

**MATH 394. Individual Study. 1-5 Credits.****MATH 399. Special Topics. 1-5 Credits.****MATH 420. Abstract Algebra I. 3 Credits.**

Groups, permutations, quotient groups, homomorphisms, rings, ideals, integers. Prereq: MATH 270 and MATH 329. {Also offered for graduate credit - see MATH 620.}

**MATH 421. Abstract Algebra II. 3 Credits.**

Division rings, integral domains, fields, field extensions, Galois Theory. Prereq: MATH 420. {Also offered for graduate credit - see MATH 621.}

**MATH 429. Topics in Linear Algebra. 3 Credits.**

Advanced topics in linear algebra with a focus on understanding the theoretical foundation of the subject and its uses in advanced mathematics. Topics may vary. Prereq: MATH 270 and MATH 329. {Also offered for graduate credit - see MATH 629.}

**MATH 430. Graph Theory. 3 Credits.**

Graphs and directed graphs, graph models, subgraphs, isomorphisms, paths, connectivity, trees, networks, cycles, circuits, planarity, Euler's formula, matchings, bipartite graphs, colorings, and selected advanced topics. Prereq: MATH 270. {Also offered for graduate credit - see MATH 630.}

**MATH 436. Combinatorics. 3 Credits.**

Recurrence relations, formal power series, generating functions, exponential generating functions, enumeration, binomial coefficients and identities, hypergeometric functions, Ramsey theory, Sterling and Eulerian numbers. Prereq: MATH 270. {Also offered for graduate credit - see MATH 636.}

**MATH 439. Topics in Algebra and Discrete Mathematics. 3 Credits.**

Advanced topics in algebra and discrete mathematics. Topics may vary but may include: algebraic geometry, factorization, partially ordered sets, and/or coding theory. Prereq: MATH 420 or MATH 430 or MATH 436. {Also offered for graduate credit - See MATH 639.}

**MATH 440. Axiomatic Geometry. 3 Credits.**

Hilbert's axioms for Euclidean geometry, projective geometry, history of parallel axiom, hyperbolic geometry, elliptic geometry. Prereq: MATH 270. {Also offered for graduate credit - see MATH 640.}

**MATH 442. Introduction to Topology. 3 Credits.**

Basic Point-Set Topology: Topological Spaces, Open/Closed Sets, Continuity, Connectedness, Compactness; Surfaces: Classification, Basic Invariants; Introduction to Homology; Applications: Brouwer's Fix-Point Theorem, Ham and Sandwich Theorem. Prereq: MATH 346. {Also offered for graduate credit - see MATH 642.}

**MATH 443. Differential Geometry. 3 Credits.**

Local and global geometry of plane curves, local geometry of hypersurfaces, global geometry of hypersurfaces, geometry of lengths and distances. Prereq: MATH 265 and MATH 346. {Also offered for graduate credit - see MATH 643.}

**MATH 449. Topics in Topology and Geometry. 3 Credits.**

Topics will vary and may include: Riemannian Geometry, Symplectic Topology, Dynamical Systems on Manifolds, Hamiltonian Systems, Geometric Group Theory, Descriptive Set Theory. Prereq: MATH 442 or MATH 443. {Also offered for graduate credit - See MATH 649}.

**MATH 450. Real Analysis I. 3 Credits.**

Differentiation and Riemann integration in the real numbers. Sequences and series of functions; uniform convergence and power series. Prereq: MATH 346. {Also offered for graduate credit - see MATH 650.}

**MATH 452. Complex Analysis. 3 Credits.**

Complex number systems, analytic and harmonic functions, elementary conformal mapping, integral theorems, power series, Laurent series, residue theorem, and contour integral. Prereq: MATH 265 and MATH 270. {Also offered for graduate credit - see MATH 652.}

**MATH 453. Introduction to Lebesgue Measure. 3 Credits.**

Definition of Lebesgue measure. Measurable and Lebesgue integrable functions. Introduction to  $L_p$  spaces. Prereq: MATH 450. {Also offered for graduate credit - see MATH 653}.

**MATH 454. Introduction to Functional Analysis. 3 Credits.**

Functional analysis in sequence spaces. Standard sequence spaces and dual spaces. Hahn-Banach Theorem. Operators on sequence spaces. Prereq: MATH 346. {Also offered for graduate credit - See MATH 654}.

**MATH 459. Topics in Analysis. 3 Credits.**

Topics will vary and may include: Harmonic Analysis, Dynamical Systems, Fractals, Distribution Theory, and Approximation Theory. Prereq: MATH 450. {Also offered for graduate credit - See MATH 659.}

**MATH 460. Mathematical Software. 1 Credit.**

An overview of a mathematical software system, with a focus on its utility in mathematical problems. Possible software systems may include: Mathematica, SAGE, or similar programs. May be repeated for credit with a different software. Prereq: MATH 259 or MATH 265. {Also offered for graduate credit - see MATH 660.}

**MATH 472. Number Theory. 3 Credits.**

Properties of integers, number theoretic functions, quadratic residues, continued fractions, prime numbers and their distribution, primitive roots. Prereq: MATH 270. {Also offered for graduate credit - see MATH 672.}

**MATH 473. Cryptology. 3 Credits.**

Cryptography and cryptanalysis of ciphers. Discrete logarithms, Diffie-Hellman key exchange, the RSA cryptosystem, elliptic curve cryptography, and selected topics. Prereq: MATH 270 and MATH 329. {Also offered for graduate credit - see MATH 673.}

**MATH 476. Actuary Exam Study. 1 Credit.**

Selected material from probability and mathematical statistics in preparation for the national actuarial exam. Prereq: STAT 368 or STAT 468. Cross-listed with STAT.

**MATH 478. History of Mathematics. 3 Credits.**

Historical considerations emphasizing the source of mathematical ideas, growth of mathematical knowledge, and contributions of some outstanding mathematicians. Prereq: MATH 270. {Also offered for graduate credit - see MATH 678.}

**MATH 480. Applied Differential Equations. 3 Credits.**

Method of power series and method of Frobenius, oscillation theorems, special functions (Bessel functions and Legendre functions), linear systems including the exponential matrix. Sturm-Liouville and phase plane analysis as time permits. Prereq: MATH 266. {Also offered for graduate credit - see MATH 680.}

**MATH 481. Fourier Analysis. 3 Credits.**

Discrete and continuous Fourier transforms, Fourier series, convergence and inversion theorems, mean square approximation and completeness, Poisson summation, Fast-Fourier transform. Prereq: MATH 265. {Also offered for graduate credit - see MATH 681.}

**MATH 483. Partial Differential Equations. 3 Credits.**

First and second order partial differential equations, classification, examples, solution methods for the wave, diffusion, and Laplace equations, causality and energy, boundary value problems, separation of variables, Green's identities, Green's functions. Prereq: MATH 266 and either MATH 270 or Math 329. {Also offered for graduate credit - see MATH 683.}

**MATH 484. Mathematical Methods of Biological Processes. 3 Credits.**

This course provides an introduction to mathematical methods in biology. Prereq: MATH 266. {Also offered for graduate credit - see MATH 684.}

**MATH 485. Topics in Applied Mathematics. 3 Credits.**

Topics will vary and may include: Models in Biology and Finance, Network Theory, Calculus of Variation, Stochastic Calculus, Integral Transforms, Control Theory, and Parameter Estimation. Prereq: MATH 483. {Also offered for graduate credit - See MATH 685.}

**MATH 488. Numerical Analysis. 3 Credits.**

Numerical solution of nonlinear equations, interpolation, numerical integration and differentiation, numerical solution of initial value problems for ordinary differential equations. Prereq: MATH 266. {Also offered for graduate credit - see MATH 688.}.

**MATH 491. Seminar. 1-5 Credits.****MATH 492. Global Practicum: Study Abroad. 1-15 Credits.**

Pre-Arranged study at accredited foreign institutions (study abroad), domestic institutions (National Student Exchange) or on approved study abroad programs. Pre-requisite: Sophomore standing and prior approval by International Student and Study Abroad Services and major department. Graded 'P' or 'F' (Undergraduate), or 'S' or 'U' (Graduate).

**MATH 493. Undergraduate Research. 1-5 Credits.****MATH 494. Individual Study. 1-5 Credits.****MATH 496. Field Experience. 1-15 Credits.****MATH 499. Special Topics. 1-5 Credits.****MATH 620. Abstract Algebra I. 3 Credits.**

Groups, permutations, quotient groups, homomorphisms, rings, ideals, integers. {Also offered for undergraduate credit - see MATH 420.}.

**MATH 621. Abstract Algebra II. 3 Credits.**

Division rings, integral domains, fields, field extensions, Galois Theory. Prereq: MATH 620. {Also offered for undergraduate credit - see MATH 421.}.

**MATH 629. Topics in Linear Algebra. 3 Credits.**

Advanced topics in linear algebra with a focus on understanding the theoretical foundation of the subject and its uses in advanced mathematics. Topics may vary. {Also offered for undergraduate credit - see MATH 429.}.

**MATH 630. Graph Theory. 3 Credits.**

Graphs and directed graphs, graph models, subgraphs, isomorphisms, paths, connectivity, trees, networks, cycles, circuits, planarity, Euler's formula, matchings, bipartite graphs, colorings, and selected advanced topics. {Also offered for undergraduate credit - see MATH 430.}.

**MATH 636. Combinatorics. 3 Credits.**

Recurrence relations, formal power series, generating functions, exponential generating functions, enumeration, binomial coefficients and identities, hypergeometric functions, Ramsey theory, Sterling and Eulerian numbers. {Also offered for undergraduate credit - see MATH 436.}.

**MATH 639. Topics in Algebra and Discrete Mathematics. 3 Credits.**

Advanced topics in algebra and discrete mathematics. Topics may vary but may include: algebraic geometry, factorization, partially ordered sets, and/or coding theory. {Also offered for undergraduate credit. See MATH 439.}.

**MATH 640. Axiomatic Geometry. 3 Credits.**

Hilbert's axioms for Euclidean geometry, projective geometry, history of parallel axiom, hyperbolic geometry, elliptic geometry. {Also offered for undergraduate credit - see MATH 440.}.

**MATH 642. Introduction to Topology. 3 Credits.**

Basic Point-Set Topology: Topological Spaces, Open/Closed Sets, Continuity, Connectedness, Compactness; Surfaces: Classification, Basic Invariants; Introduction to Homology; Applications: Brouwer's Fix-Point Theorem, Ham and Sandwich Theorem. {Also offered for undergraduate credit - see MATH 442.}.

**MATH 643. Differential Geometry. 3 Credits.**

Local and global geometry of plane curves, local geometry of hypersurfaces, global geometry of hypersurfaces, geometry of lengths and distances. {Also offered for undergraduate credit - see MATH 443.}.

**MATH 649. Topics in Topology and Geometry. 3 Credits.**

Topics will vary and may include: Riemannian Geometry, Symplectic Topology, Dynamical Systems on Manifolds, Hamiltonian Systems, Geometric Group Theory, Descriptive Set Theory. {Also offered for undergraduate credit - See MATH 449.}.

**MATH 650. Real Analysis I. 3 Credits.**

Differentiation and Riemann integration in the real numbers. Sequences and series of functions; uniform convergence and power series. {Also offered for undergraduate credit - see MATH 450.}.

**MATH 652. Complex Analysis. 3 Credits.**

Complex number systems, analytic and harmonic functions, elementary conformal mapping, integral theorems, power series, Laurent series, residue theorem, and contour integral. {Also offered for undergraduate credit - see MATH 452.}.

**MATH 653. Introduction to Lebesgue Measure. 3 Credits.**

Definition of Lebesgue measure. Measurable and Lebesgue integrable functions. Introduction to  $L_p$  spaces. {Also offered for undergraduate credit - see MATH 453.}.

**MATH 654. Introduction to Functional Analysis. 3 Credits.**

Functional analysis in sequence spaces. Standard sequence spaces and dual spaces. Hahn-Banach Theorem. Operators on sequence spaces. {Also offered for undergraduate credit - See MATH 454.}.

**MATH 659. Topics in Analysis. 3 Credits.**

Topics will vary and may include: Harmonic Analysis, Dynamical Systems, Fractals, Distribution Theory, and Approximation Theory. {Also offered for undergraduate credit - See MATH 459.}

**MATH 660. Mathematical Software. 1 Credit.**

An overview of a mathematical software system, with a focus on its utility in mathematical problems. Possible software systems may include: Mathematica, SAGE, or similar programs. May be repeated for credit with a different software. {Also offered for undergraduate credit - see MATH 460.}

**MATH 672. Number Theory. 3 Credits.**

Properties of integers, number theoretic functions, quadratic residues, continued fractions, prime numbers and their distribution, primitive roots. {Also offered for undergraduate credit - see MATH 472.}

**MATH 673. Cryptology. 3 Credits.**

Cryptography and cryptanalysis of ciphers. Discrete logarithms, Diffie-Hellman key exchange, the RSA cryptosystem, elliptic curve cryptography, and selected topics. {Also offered for undergraduate credit - see MATH 473.}

**MATH 678. History of Mathematics. 3 Credits.**

Historical considerations emphasizing the source of mathematical ideas, growth of mathematical knowledge, and contributions of some outstanding mathematicians. {Also offered for undergraduate credit - see MATH 478.}

**MATH 680. Applied Differential Equations. 3 Credits.**

Method of power series and method of Frobenius, oscillation theorems, special functions (Bessel functions and Legendre functions), linear systems including the exponential matrix. Sturm-Liouville and phase plane analysis as time permits. {Also offered for undergraduate credit - see MATH 480.}

**MATH 681. Fourier Analysis. 3 Credits.**

Discrete and continuous Fourier transforms, Fourier series, convergence and inversion theorems, mean square approximation and completeness, Poisson summation, Fast-Fourier transform. {Also offered for undergraduate credit - see MATH 481.}

**MATH 683. Partial Differential Equations. 3 Credits.**

First and second order partial differential equations, classification, examples, solution methods for the wave, diffusion, and Laplace equations, causality and energy, boundary value problems, separation of variables, Green's identities, Green's functions. {Also offered for undergraduate credit - see MATH 483.}

**MATH 684. Mathematical Methods of Biological Processes. 3 Credits.**

This course provides an introduction to mathematical methods in biology. {Also offered for undergraduate credit - see MATH 484.}

**MATH 685. Topics in Applied Mathematics. 3 Credits.**

Topics will vary and may include: Models in Biology and Finance, Network Theory, Calculus of Variation, Stochastic Calculus, Integral Transforms, Control Theory, and Parameter Estimation. {Also offered for undergraduate credit - See MATH 485.}

**MATH 688. Numerical Analysis. 3 Credits.**

Numerical solution of nonlinear equations, interpolation, numerical integration and differentiation, numerical solution of initial value problems for ordinary differential equations. {Also offered for undergraduate credit - see MATH 488.}

**MATH 690. Graduate Seminar. 1-3 Credits.****MATH 696. Special Topics. 1-5 Credits.****MATH 720. Algebra I. 3 Credits.**

Graduate level survey of algebra: rings, modules, linear algebra and selected advanced topics. Prereq: MATH 621.

**MATH 721. Algebra II. 3 Credits.**

Graduate level survey of algebra: groups, fields, Galois theory, and selected advanced topics. Prereq: MATH 720.

**MATH 726. Homological Algebra. 3 Credits.**

An overview of the techniques of homological algebra. Topics covered will include categories and functors, exact sequences, (co)chain complexes, Mayer-Vietoris sequences, TOR and EXT. Applications to other fields will be stressed. Prereq: MATH 720.

**MATH 732. Introduction to Bioinformatics. 3 Credits.**

An introduction to the principles of bioinformatics including information relating to the determination of DNA sequencing. Prereq: STAT 661. Cross-listed with CSCI 732 and STAT 732.

**MATH 736. Enumerative Combinatorics. 3 Credits.**

Combinatorial enumeration, generating functions, inversion formulae, formal power series, and selected advanced topics. Prereq: MATH 636.

**MATH 737. Algebraic Combinatorics. 3 Credits.**

Posets, distributive lattices, tableaux dynamics, symmetric functions, representation theory, and selected advanced topics. Prereq: MATH 636.

**MATH 746. Topology I. 3 Credits.**

Topological spaces, convergence and continuity, separation axioms, compactness, connectedness, metrizability, fundamental group and homotopy theory. Advanced topics may include homology theory, differential topology, three-manifold theory and knot theory. Prereq: MATH 642.

**MATH 747. Topology II. 3 Credits.**

Topological spaces, convergence and continuity, separation axioms, compactness, connectedness, metrizable, fundamental group and homotopy theory. Advanced topics may include homology theory, differential topology, three-manifold theory and knot theory. Prereq: MATH 642.

**MATH 750. Analysis. 3 Credits.**

Lebesgue and general measure and integration theory, differentiation, product spaces, metric spaces, elements of classical Banach spaces, Hilbert spaces, and selected advanced topics. Prereq: MATH 650.

**MATH 752. Complex Analysis. 3 Credits.**

Analytic and harmonic functions, power series, conformal mapping, contour integration and the calculus of residues, analytic continuation, meromorphic and entire functions, and selected topics. Prereq: MATH 652.

**MATH 754. Functional Analysis. 3 Credits.**

Normed spaces, linear maps, Hahn-Banach Theorem and other fundamental theorems, conjugate spaces and weak topology, adjoint operators, Hilbert spaces, spectral theory, and selected topics. Prereq: MATH 750.

**MATH 756. Harmonic Analysis. 3 Credits.**

A survey of Harmonic analysis including:  $L_p$  spaces; Fourier Series; Fourier transform; Hilbert transform; and special selected topics. Prereq: MATH 750.

**MATH 760. Ordinary Differential Equations I. 3 Credits.**

Existence, uniqueness, and extensibility of solutions to initial value problems, linear systems, stability, oscillation, boundary value problems, and selected advanced topics. Prereq: MATH 650 or MATH 680.

**MATH 782. Mathematical Methods in Physics I. 3 Credits.**

Review of practical mathematical methods routinely used by physicists, including applications. Focus on differential equations, variational principles, and other selected topics. Cross-listed with PHYS 752.

**MATH 783. Mathematical Methods in Physics II. 3 Credits.**

Tensor analysis, matrices and group theory, special relativity, integral equations and transforms, and selected advanced topics. Prereq: MATH 629 and MATH 652. Cross-listed with PHYS 753.

**MATH 784. Partial Differential Equations I. 3 Credits.**

Classification in elliptic, parabolic, hyperbolic type; existence and uniqueness for second order equations; Green's functions, and integral representations; characteristics, nonlinear phenomena. Prereq: MATH 650 or MATH 683.

**MATH 790. Graduate Seminar. 1-3 Credits.****MATH 791. Temporary/Trial Topics. 1-5 Credits.****MATH 793. Individual Study/Tutorial. 1-5 Credits.****MATH 794. Practicum/Internship. 1-8 Credits.****MATH 796. Special Topics. 1-5 Credits.****MATH 797. Master's Paper. 1-3 Credits.****MATH 798. Master's Thesis. 1-10 Credits.****MATH 810. Research in the Teaching of University Mathematics. 3 Credits.**

This course will cover fundamental topics in mathematics education research including: research design, fundamental research areas, and the interconnection between research and classroom practices.

**MATH 824. Topics in Commutative Algebra. 3 Credits.**

Topics vary each time the course is offered and may include: dimension theory, integral dependence, factorization, regular rings, Cohen-Macaulay rings, Gorenstein rings. May be repeated for credit with change in subtopic. Prereq: MATH 720.

**MATH 825. Theory Of Rings. 3 Credits.**

The ideal theory of commutative rings, structure of (non-commutative) rings, and selected advanced topics. Prereq: MATH 720.

**MATH 830. Graph Theory. 3 Credits.**

Graduate-level survey of graph theory: paths, connectivity, trees, cycles, planarity, genus, Eulerian graphs, Hamiltonian graphs, factorizations, tournaments, embedding, isomorphism, subgraphs, colorings, Ramsey theory, girth. Prereq: MATH 630.

**MATH 839. Topics in Combinatorics and Discrete Mathematics. 3 Credits.**

Selected topics in combinatorics and discrete mathematics. Topics vary each time the course is offered and may include: symmetric functions, Coxeter theory, geometric combinatorics of polytopes, computational combinatorics, statistical mechanics and combinatorics, or dynamical algebraic combinatorics.

**MATH 849. Topics in Geometry & Topology. 3 Credits.**

Advanced topics in Geometry and/or Topology. Topics vary but may include: differential geometry, K-theory, knot theory, or noncommutative geometry. May be repeated for credit with change in subtopic. Prereq: MATH 642, MATH 643.

**MATH 856. Dynamical Systems. 3 Credits.**

A study of basic notions of topological and symbolic dynamics. Introduction to measurable dynamics and ergodic theory. Ergodicity, mixing and entropy of dynamical systems. Prereq: MATH 750.

**MATH 857. Topics in Functional Analysis. 3 Credits.**

Maximal monotone operators and the Hille-Yosida theorem, Sobolev spaces in dimension one and applications, Sobolev spaces in higher dimensions, extension operators, Sobolev embedding theorems, Poincare inequality, duality. May be repeated for credit with change in subtopic. Prereq: MATH 750. Co-req: MATH 751.

**MATH 861. Ordinary Differential Equations II. 3 Credits.**

Existence, uniqueness, and extendibility of solutions to initial value problems, linear systems, stability, oscillation, boundary value problems, difference equations, and selected advanced topics. Prereq: MATH 760.

**MATH 862. Integral Equations. 3 Credits.**

Existence and uniqueness of solutions of Fredholm and Volterra integral equations, Fredholm Theory, singular integral equations, and selected advanced topics. Prereq: MATH 650.

**MATH 864. Calculus Of Variations. 3 Credits.**

Variational techniques of optimization of functionals, conditions of Euler, Weierstrass, Legendre, Jacobi, Erdmann, Pontryagin Maximal Principle, applications, and selected advanced topics. Prereq: MATH 650.

**MATH 867. Topics in Applied Mathematics. 3 Credits.**

Topics will vary and may include: Optimal Control, Robust Control, Stability Analysis, Mathematics of Networks, Models in Biology, Levy Processes, Asymptotic Expansions. May be repeated for credit with change in subtopic. Prereq: MATH 650 or MATH 680.

**MATH 878. Modern Probability Theory. 3 Credits.**

Probability theory presented from the measure theoretic perspective. Emphasis on various types of convergence and limit theorems. Discussion of random walks, conditional expectations, and martingales. Prereq: STAT 768 or MATH 750. Cross-listed with STAT 778.

**MATH 880. Methods of Optimization. 3 Credits.**

Elements of convex analysis, constrained and unconstrained multi-dimensional linear and nonlinear optimization theory and algorithms, convergence properties and computational complexity. Prereq: CSCI 653. Cross-listed with CSCI 880.

**MATH 881. Mathematical Control Theory. 3 Credits.**

Standard optimal control and optimal estimation problems; duality; optimization in Hardy space; robust control design. Prereq: MATH 650.

**MATH 885. Partial Differential Equations II. 3 Credits.**

Nonlinear partial differential equations, Non-variational techniques, Hamilton-Jacobi equations, Riemann invariants, Entropy/entropy-flux pairs, selected advanced topics. Prereq: MATH 784.

**MATH 888. Numerical Analysis. 3 Credits.**

Numerical solutions to partial differential and integral equations, error analysis, stability, acceleration of convergence, numerical approximation, and selected advanced topics. Prereq: MATH 688.

**MATH 893. Individual Study/Tutorial. 1-5 Credits.****MATH 899. Doctoral Dissertation. 1-15 Credits.**