

# MATH - MATHEMATICS

## MATH 601 Methods of Applied Mathematics I

**Credits 3. 3 Lecture Hours.**

Methods of linear algebra, vector analysis and complex variables.

**Prerequisite:** MATH 308 or equivalent.

## MATH 602 Methods and Applications of Partial Differential Equations

**Credits 3. 3 Lecture Hours.**

Classification of linear partial differential equations of the second order; Fourier series, orthogonal functions, applications to partial differential equations; special functions, Sturm-Liouville theory, application to boundary value problems; introduction to Green's functions; finite Fourier transforms.

**Prerequisites:** MATH 601 or MATH 308 and MATH 407.

## MATH 603 Methods of Applied Mathematics II

**Credits 3. 3 Lecture Hours.**

Tensor algebra and analysis; partial differential equations and boundary value problems; Laplace and Fourier transform methods for partial differential equations.

**Prerequisite:** MATH 601 or MATH 311.

## MATH 604 Mathematical Foundations of Continuum Mechanics

**Credits 3. 3 Lecture Hours.**

Mathematical description of continuum mechanics principles, including: tensor analysis, generalized description of kinematics and motion, conservation laws for mass and momentum; invariance and symmetry principles; application to generalized formulation of constitutive expressions for various fluids and solids.

**Prerequisites:** MATH 410; MATH 451 or equivalent.

## MATH 605 Mathematical Fluid Dynamics

**Credits 3. 3 Lecture Hours.**

Derivation of basic equations of motion; Navier-Stokes equations; potential equations; some exact solutions in two and three dimensions; equations of boundary layer theory; vorticity-stream function formulation and vortex dynamics; introduction to hydrodynamic stability; introduction to equations of turbulence.

**Prerequisite:** MATH 601 or equivalent.

## MATH 606 Theory of Probability I

**Credits 3. 3 Lecture Hours.**

Measure and integration, convergence concepts, random variables, independence and conditional expectation, laws of large numbers, central limit theorems, applications.

**Prerequisite:** MATH 607 or approval of instructor.

## MATH 607 Real Variables I

**Credits 3. 3 Lecture Hours.**

Lebesgue measure and integration theory, differentiation,  $L_p$ -spaces, abstract integration, signed measures; Radon-Nikodym theorem, Riesz representation theorem, integration on product spaces.

**Prerequisite:** MATH 447 or equivalent.

## MATH 608 Real Variables II

**Credits 3. 3 Lecture Hours.**

Banach spaces, theorems of Hahn-Banach and Banach-Steinhaus, the closed graph and open mapping theorems, Hilbert spaces, topological vector spaces and weak topologies.

**Prerequisite:** MATH 607.

## MATH 609 Numerical Analysis

**Credits 4. 3 Lecture Hours. 3 Lab Hours.**

Interpolation, numerical evaluation of definite integrals and solution of ordinary differential equations; stability and convergence of methods and error estimates.

**Prerequisite:** Knowledge of computer programming (C or FORTRAN).

## MATH 610 Numerical Methods in Partial Differential Equations

**Credits 4. 3 Lecture Hours. 3 Lab Hours.**

Introduction to finite difference and finite element methods for solving partial differential equations; stability and convergence of methods and error bounds.

**Prerequisite:** MATH 417 or MATH 609 or equivalent; knowledge of computer programming.

## MATH 611 Introduction to Ordinary and Partial Differential Equations

**Credits 3. 3 Lecture Hours.**

Basic theory of ordinary differential equations; existence and uniqueness, dependence on parameters, phase portraits, vector fields. Partial differential equations of first order, method of characteristics. Basic linear partial differential equations: Laplace equation, heat (diffusion) equation, wave equation and transport equation. Solution techniques and qualitative properties.

**Prerequisite:** MATH 410 or equivalent or instructor's approval.

## MATH 612 Partial Differential Equations

**Credits 3. 3 Lecture Hours.**

Theory of linear partial differential equations; Sobolev spaces; elliptic equations (including boundary value problems and spectral theory); linear evolution equations of parabolic and hyperbolic types (including initial and boundary value problems). As time permits, additional topics might be included.

**Prerequisite:** MATH 611 and MATH 607 or MATH 641, or approval of instructor.

## MATH 613 Graph Theory

**Credits 3. 3 Lecture Hours.**

One or more broad areas of graph theory or network theory, such as planarity, connectivity, Hamiltonian graphs, colorings of graphs, automorphisms of graphs, or network theory.

**Prerequisite:** MATH 431 or equivalent or approval of instructor.

## MATH 614 Dynamical Systems and Chaos

**Credits 3. 3 Lecture Hours.**

Discrete maps; continuous flows; dynamical systems; Poincaré maps; symbolic dynamics; chaos, strange attractors; fractals; computer simulation of dynamical systems.

**Prerequisites:** MATH 308; MATH 601 or equivalent.

## MATH 615 Introduction to Classical Analysis

**Credits 3. 3 Lecture Hours.**

Set-theoretic preliminaries; Cantor-Schröder-Bernstein Theorem; review of sequences; limit inferior and limit superior; infinite products; metric spaces; convergence of functions; Dini's Theorem, Weierstrass Approximation Theorem; Monotone functions; bounded variation; Helly's Selection Theorem; Riemann-Stieltjes integration; Fourier series; Fejér's Theorem; Parseval's Identity; Bernstein's Theorem on absolutely convergent Fourier series.

**Prerequisite:** MATH 409 or equivalent.

## MATH 617 Theory of Functions of a Complex Variable I

**Credits 3. 3 Lecture Hours.**

Holomorphic functions, complex integral theorems, Runge's theorem, residue theorem, Laurent series, conformal mapping, harmonic functions.

**Prerequisite:** MATH 410.

**MATH 618 Theory of Functions of a Complex Variable II****Credits 3. 3 Lecture Hours.**

Infinite products, Weierstrass factorization theorem, Mittag-Leffler's theorem, normal families, Riemann mapping theorem, analytic continuation, Picard's theorems and selected topics.

**Prerequisite:** MATH 617.**MATH 619 Applied Probability****Credits 3. 3 Lecture Hours.**

Measure Theory; Lebesgue integration; random variables; expectation; condition expectation martingales and random walks; designed for beginning graduate students in mathematics, statistics, the sciences and engineering and students in economics and finance with a strong mathematical background.

**Prerequisites:** MATH 409 and MATH 411.**MATH 620 Algebraic Geometry I****Credits 3. 3 Lecture Hours.**

Affine and projective varieties; sheaves; cohomology; Riemann-Roch Theorem for curves.

**Prerequisite:** MATH 653 or approval of instructor.**MATH 622 Differential Geometry I****Credits 3. 3 Lecture Hours.**

Surfaces in 3-D space and generalizations to submanifolds of Euclidean space; smooth manifolds and mappings; tensors; differential forms; Lie groups and algebras; Stokes' theorem; deRham cohomology; Frobenius theorem; Riemannian manifolds.

**Prerequisites:** MATH 304 or equivalent; approval of instructor.**MATH 623 Differential Geometry II****Credits 3. 3 Lecture Hours.**

Curvature of Riemannian manifolds; vector bundles; connections; Maurer-Cartan Form; Laplacian; geodesics; Chern-Gauss-Bonnet theorem; additional topics to be selected by the instructor.

**Prerequisites:** MATH 622 or approval of instructor.**MATH 625 Applied Stochastic Differential Equations****Credits 3. 3 Lecture Hours.**

Stochastic integration, Ito Calculus and applications of stochastic differential equations to finance and engineering.

**Prerequisite:** MATH 619.**MATH 626 Analytic Number Theory****Credits 3. 3 Lecture Hours.**

Analytic properties of the Riemann zeta function and Dirichlet L-functions; Dirichlet characters; prime number theorem; distribution of primes in arithmetic progressions; Siegel's theorem; the large sieve inequalities; Bombieri-Vinogradov theorem.

**Prerequisite:** MATH 617.**MATH 627 Algebraic Number Theory****Credits 3. 3 Lecture Hours.**

Algebraic number fields and rings of algebraic integers; arithmetic in algebraic number fields; ideals; unique factorization of ideals; ideal classes and the class group; finiteness of the class number; Minkowski's theorem; Dirichlet's unit theorem; quadratic and cyclotomic number fields; splitting of primes in extension fields.

**Prerequisite:** MATH 653 or approval of instructor.**MATH 628 Mathematics of Finance****Credits 3. 3 Lecture Hours.**

Pricing of financial derivatives in different market models; discrete models: Arrow-Debreu, Binomial model, Hedging; Stochastic calculus; Brownian Motion, stochastic integrals, Ito formula; continuous model: Black-Scholes formula for pricing European and American options; equivalent Martingale Measures, pricing of exotic options.

**Prerequisite:** MATH 606 or MATH 619 or approval of instructor.**MATH 629 History of Mathematics****Credits 3. 3 Lecture Hours.**

Major events in the evolution of mathematical thought from ancient times to the present, the development of various important branches of mathematics, including numeration, geometry, algebra, analysis, number theory, probability, and applied mathematics.

**Prerequisite:** MATH 304 or equivalent.**MATH 630 Combinatorics****Credits 3. 3 Lecture Hours.**

This is an introduction at the graduate level to the fundamental ideas and results of combinatorics, including enumerative techniques, sieve methods, partially ordered sets and generating functions.

**Prerequisite:** undergraduate discrete math course or permission of instructor.**MATH 636 Topology I****Credits 3. 3 Lecture Hours.**

Set theory, topological spaces, generalized convergence, compactness, metrization, connectedness, uniform spaces, function spaces.

**Prerequisite:** Approval of instructor.**MATH 637 Topology II****Credits 3. 3 Lecture Hours.**

Continuation of MATH 636.

**Prerequisite:** MATH 636 or approval of instructor.**MATH 638 Hyperbolic Conservation Laws****Credits 3. 3 Lecture Hours.**

Introduction to basic theory and numerical methods for first order nonlinear partial differential equations; basic existence-uniqueness theory for scalar conservation laws; special equations and systems of interest in various applications and Riemann problem solutions for such systems; design of numerical methods for general hyperbolic systems; stability and convergence properties of numerical methods.

**Prerequisite:** MATH 610 or MATH 612 or approval of instructor.**MATH 639 Iterative Techniques****Credits 4. 3 Lecture Hours. 3 Lab Hours.**

Numerical methods for solving linear and nonlinear equations and systems of equations; eigenvalue problems.

**Prerequisites:** Elementary linear algebra and knowledge of computer programming (C or FORTRAN).**MATH 640 Linear Algebra for Applications****Credits 3. 3 Lecture Hours.**

Review of linear algebra; spectral theory in inner product spaces; decomposition theorems; duality theory and multilinear algebra; tensor products; applications. May be taken concurrently with MATH 641.

**Prerequisite:** MATH 304 or equivalent.

**MATH 641 Analysis for Applications I****Credits 3. 3 Lecture Hours.**

Review of preliminary concepts; sequence and function spaces; normed linear spaces, inner product spaces; spectral theory for compact operators; fixed point theorems; applications to integral equations and the calculus of variations.

**Prerequisites:** MATH 447 and MATH 640 or approval of instructor.

**MATH 642 Analysis for Applications II****Credits 3. 3 Lecture Hours.**

Distributions and differential operators; transform theory; spectral theory for unbounded self-adjoint operators; applications to partial differential equations; asymptotics and perturbation theory.

**Prerequisite:** MATH 641.

**MATH 643 Algebraic Topology I****Credits 3. 3 Lecture Hours.**

Fundamental ideas of algebraic topology, homotopy and fundamental group, covering spaces, polyhedra.

**Prerequisite:** Approval of instructor.

**MATH 644 Algebraic Topology II****Credits 3. 3 Lecture Hours.**

Homology and cohomology theory.

**Prerequisite:** MATH 643.

**MATH 645 A Survey of Mathematical Problems I****Credits 3. 3 Lecture Hours.**

A survey of problems in various branches of mathematics, such as logic, probability, graph theory, number theory, algebra and geometry.

**Prerequisites:** MATH 409, MATH 415, MATH 423 or approval of instructor.

**MATH 646 A Survey of Mathematical Problems II****Credits 3. 3 Lecture Hours.**

A survey of problems in various branches of mathematics such as algebra, geometry, differential equations, real analysis, complex analysis, calculus of variations.

**Prerequisite:** MATH 645 or approval of instructor.

**MATH 647 Mathematical Modeling****Credits 3. 3 Lecture Hours.**

The process and techniques of mathematical modeling; covers a variety of application areas and models such as ordinary and partial differential equations, stochastic models, discrete models and problems involving optimization.

**Prerequisite:** MATH 442 or approval of instructor.

**MATH 648 Computational Algebraic Geometry****Credits 3. 3 Lecture Hours.**

Broad introduction to algorithmic algebraic geometry, including numerical and complexity theoretic aspects; theory behind the most efficient modern algorithms for polynomial system solving and the best current quantitative/geometric estimates on algebraic sets over various rings is derived.

**Prerequisite:** MATH 653 or approval of instructor.

**MATH 650 Several Complex Variables****Credits 3. 3 Lecture Hours.**

Introduction to function theory in several complex variables with an emphasis on the analytic and partial differential equations aspects of the subject.

**Prerequisites:** MATH 608 and MATH 618 or equivalents.

**MATH 651 Optimization I****Credits 3. 3 Lecture Hours.**

Fundamentals of mathematical analysis underlying theory of constrained optimizations for a finite number of variables, necessary and sufficient conditions for constrained extrema of equality constraint problems, sufficient conditions for fulfillment of constraint qualification, computational methods for concave programming problems and applications.

**Prerequisite:** MATH 410 or approval of instructor.

**MATH 652 Optimization II****Credits 3. 3 Lecture Hours.**

Necessary conditions of calculus of variations, elementary theory of games, formulation of basic control problem, Hestenes' necessary conditions for optimal control, transformations, methods of computation and applications.

**Prerequisite:** MATH 651.

**MATH 653 Algebra I****Credits 3. 3 Lecture Hours.**

Survey of groups, rings, ideals.

**Prerequisite:** MATH 415 or approval of instructor.

**MATH 654 Algebra II****Credits 3. 3 Lecture Hours.**

Survey of modules, field extensions, Galois theory.

**Prerequisite:** MATH 653 or approval of instructor.

**MATH 655 Functional Analysis I****Credits 3. 3 Lecture Hours.**

Normed linear spaces, duality theory, reflexivity, operator theory. Banach algebras, spectral theory, representation theory.

**Prerequisite:** MATH 608.

**MATH 656 Functional Analysis II****Credits 3. 3 Lecture Hours.**

Topological linear spaces, locally convex spaces, duality in locally convex spaces, ordered topological vector spaces, distribution theory, applications to analysis.

**Prerequisite:** MATH 655.

**MATH 658 Applied Harmonic Analysis****Credits 3. 3 Lecture Hours.**

Fourier series and Fourier Transform; discrete (fast) Fourier transform; discrete cosine transform; local cosine transform; Radon transform; filters; harmonic analysis on the sphere; radial, periodic and spherical basis functions; applications.

**Prerequisites:** MATH 304; MATH 308 or equivalent.

**MATH 660/CSCE 660 Computational Linear Algebra****Credits 3. 3 Lecture Hours.**

Techniques in matrix computation including elimination methods, matrix decomposition, generalized inverses, orthogonalization and least-squares, eigenvalue problems and singular value decomposition, iterative methods and error analysis.

**Prerequisite:** MATH 417 or equivalent or CSCE 442 or equivalent.

**Cross Listing:** CSCE 660/MATH 660.

**MATH 661 Mathematical Theory of Finite Element Methods****Credits 3. 3 Lecture Hours.**

Will develop basic mathematical theory of finite element method; construction of finite element spaces and piece-wise polynomial approximation; Ritz-Galerkin methods and variational crimes; energy and maximum norm estimates; mixed finite element method; applications to diffusion-reaction problems.

**MATH 662 Seminar in Algebra****Credits 3. 3 Lecture Hours.**

Problems, methods and recent developments in algebra. May be repeated for credit.

**Prerequisite:** Approval of instructor.**MATH 663 Seminar in Analysis****Credits 3. 3 Lecture Hours.**

Problems, methods and recent developments in analysis. May be repeated for credit.

**Prerequisite:** Approval of instructor.**MATH 664 Seminar in Applied Mathematics****Credits 3. 3 Lecture Hours.**

Problems, methods and recent developments in applied mathematics. May be repeated for credit.

**Prerequisite:** Approval of instructor.**MATH 666 Seminar in Geometry****Credits 3. 3 Lecture Hours.**

Problems, methods and recent developments in geometry. May be repeated for credit.

**Prerequisite:** Approval of instructor.**MATH 667 Foundations and Methods of Approximation****Credits 3. 3 Lecture Hours.**

Existence, uniqueness and characterization of best approximations; polynomial and rational approximants; Bernstein polynomials; Bernstein and Markov inequalities; ridge functions; approximation from shift-invariant subspaces; orthogonal polynomials; neural networks, radial basis functions, scattered-data surface fitting; subdivision analysis.

**Prerequisites:** MATH 407 and MATH 409.**MATH 669 Seminar in Mathematical Biology****Credits 3. 3 Lecture Hours.**

Problems, methods and recent developments in Mathematical Biology. May be repeated for credit.

**Prerequisite:** Approval of instructor.**MATH 670 Applied Mathematics I****Credits 3. 3 Lecture Hours.**

Mathematical tools of applied mathematics; Fredholm alternative; integral operators; Green's functions; unbounded operators; Stone's theorem; distributions; convolutions; Fourier transforms; applications.

**Prerequisite:** MATH 642 or equivalent.**MATH 672 Hydrodynamic Stability****Credits 3. 3 Lecture Hours.**

Instability mechanisms; instability of interfacial and free surface flows; thermal instability, centrifugal instability, instability of inviscid and viscous parallel shear flows; fundamental concepts and applications of nonlinear instability; the onset of turbulence; various transitions to turbulence.

**Prerequisites:** MATH 601 or equivalent; MATH 605 or equivalent.**MATH 673 Information, Secrecy and Authentication I****Credits 3. 3 Lecture Hours.**

Preliminaries; probability, information, entropy, signals, channels: group-theoretic view of messages: contemporary secrecy and digital signature systems; one-time pads, DES, RSA, DSS, wheels, LFSR-based systems; analog scramblers; key exchange, key management, secret sharing, access structures; measures of security.

**Prerequisites:** Graduate classification and approval of instructor.**MATH 676 Finite Element Methods in Scientific Computing****Credits 3. 3 Lecture Hours.**

Basic finite element methods; structure of finite element codes; assembling linear systems of equations and algorithmic aspects; linear iterative solvers; adaptive mesh refinement; vector-valued and mixed problems; nonlinear problems; visualization; parallelization aspects. Additional topics may be chosen by instructor.

**Prerequisites:** MATH 610; ENGR finite element class on MATH 419 or MATH 609; approval of instructor. Knowledge of C++.**MATH 684 Professional Internship****Credits 1 to 6. 1 to 6 Other Hours.**

Directed internship in an organization to provide students with professional experience in organization settings appropriate to the student's career objectives.

**Prerequisite:** Approval of department head.**MATH 685 Directed Studies****Credits 1 to 6. 1 to 6 Other Hours.**

Offered to enable students to undertake and complete, with credit, limited investigations not within their thesis research and not covered by any other courses in the curriculum.

**Prerequisite:** Approval of instructor.**MATH 689 Special Topics in...****Credits 1 to 4. 1 to 4 Lecture Hours.**

Selected topics in an identified area of mathematics. May be repeated for credit.

**Prerequisite:** Approval of instructor.**MATH 691 Research****Credits 1 to 23. 1 to 23 Other Hours.**

Research for thesis or dissertation.

**MATH 695 Frontiers in Mathematical Research****Credits 3. 3 Lecture Hours.**

This course is designed to acquaint the graduate student with the present status of investigative work in a variety of mathematical fields. Content will depend on the availability of visiting lecturers who will be selected because of distinguished international recognition in their fields of research. May be taken two times for credit.

**Prerequisite:** Graduate classification.**MATH 696 Mathematical Communication and Technology****Credits 3. 3 Lecture Hours.**

Techniques of oral, written and electronic communication of mathematics; effective classroom and seminar presentation; LATEX, HTML and Javascript; developing Internet applications; Maple and Matlab; classroom use of computer graphics.

**Prerequisite:** Approval of instructor.