MATHEMATICS 2013–2014

Why study mathematics at the University of Denver?

Our graduate programs provide a personalized, congenial and rewarding educational atmosphere. You will interact with our faculty from your first day at the University of Denver. The Department of Mathematics at the University of Denver offers an MA and MS in mathematics and a PhD in mathematics.

Your options for involvement in mathematical research are numerous and varied; our faculty is active in research and eager to partner with you. While the department is large enough to provide high quality research opportunities, it is small enough to guarantee close faculty-student interaction. The faculty is highly distinguished, having received awards for excellence in both research and teaching.

The MS and MA degrees prepare the practitioner for careers in which mathematics plays a central role. The PhD is a research degree that prepares the recipient to advance the frontiers of knowledge within a specific area of interest. It is structured to provide the flexibility for students to incorporate interests in allied fields.

Our graduates are highly sought, not only for their knowledge of mathematics, but also for their ability to solve problems, to think abstractly and to see the big picture, and to articulate their ideas with clarity and precision. Our graduates have been successful in a remarkably diverse collection of careers, including industry, business, education and academia.

UNIVERSITY of DENVER

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Denver, CO 80208
303-871-2911
http://www.du.edu/nsm/departments/mathematics

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DEGREE REQUIREMENTS

The official departmental requirements for the MA, MS and PhD degrees are available upon request from the Department of Mathematics or can be accessed online at www.du.edu/nsm/departments/mathematics. The following description serves as a guideline. Every student's course of study must be approved in consultation with a designated departmental adviser.

Master of Arts in Mathematics

This degree requires completion of 45 quarter hours of graduate- level courses, including 12 hours of approved mathematics courses at the 4000 level. At most 10 hours of courses from another university may count toward the degree. No thesis is required.

Master of Science in Mathematics

This degree requires completion of 45 quarter hours of graduate- level courses, including 12 hours of approved mathematics courses at the 4000 level. Up to 15 hours may be in an approved cognate area. At most 10 hours of courses from another university may count toward the degree.

Demonstrated competency in a tool is required and may be chosen from among the following: proficiency in the use of a modern computing typesetting system; outside courses; laboratory experience; or reading competency in French, German or Russian. No thesis is required.

Doctor of Philosophy in Mathematics

This degree requires completion of at least 135 quarter hours (see details below) beyond the BA or BS degree; completion of a written dissertation that makes a significant contribution to the research literature in mathematics; completion of a tool requirement. Although a master's degree is not a prerequisite for acceptance into the PhD program, each student is required to obtain a master's degree in mathematics as soon as possible upon completion of 45 hours in the PhD program.

Course Requirements

Of the 135 hours, at least 36 must be at the 4000 level. Up to 35 credits may be taken in other relevant disciplines, as approved by the mathematics department graduate committee. Courses should be chosen in consultation with, and are subject to the approval of, the student's academic advisor.

Examinations

Every student admitted to the PhD program is expected to pass a written preliminary examination in analysis and a written preliminary examination in algebra. Both preliminary examinations are designed to test whether students in the PhD program have the adequate undergraduate preparation to continue in the program with a reasonable chance of success. Both examinations are offered twice per year: during the week immediately preceding the first week of the fall quarter, and during the first week of the winter quarter. A student must pass both exams by no later than the end of the winter quarter of his/her second year in the program unless the graduate committee grants an extension of this deadline for exceptional and documented reasons.

Tool Requirement

It is strongly recommended that students satisfy their tool requirement by demonstrating the ability to use a modern computer typesetting system. Other options include: reading competency in two languages selected from French, German and Russian; a series of outside courses in another discipline; a significant laboratory experience involving mathematics.

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FACULTY

Alvaro Arias
Professor
PhD, Texas A&M University
Areas of interest: functional analysis, operator algebras, probability and convex geometry

Natasha Dobrinen
Associate Professor
PhD, University of Minnesota
Areas of interest: set theory, Boolean algebras, mathematical logic, and foundations of mathematics

Nikolaos Galatos
Associate Professor PhD, Vanderbilt
Areas of interest: lattice theory, ordered algebras, mathematical logic

Paul Horn
Assistant Professor
PhD, University of California, San Diego
Areas of interest: spectral graph theory, probabilistic combinatorics

Michael Kinyon
Professor
PhD, University of Utah
Areas of interest: nonassociative algebra, loops and quasigroups, Leibniz algebras

Frédéric Latrémolière
Associate Professor
PhD, University of California-Berkeley
Areas of interest: C*-algebras, C*-dynamics

Andrew Linshaw
Assistant Professor
PhD, Brandeis University
Areas of interest: representation theory, invariant theory, vertex algebras, infinite-dimensional Lie algebras

Nicholas S. Ormes
Associate Professor
PhD, University of Maryland, College Park
Areas of interest: topological dynamics, tiling problems, ordered algebra

Ronnie Pavlov
Assistant Professor
PhD, Ohio State University
Areas of interest: dynamical systems, ergodic theory, symbolic dynamics

Petr Vojtěchovský
Professor and Interim Chair
PhD, Iowa State University PhD, Charles University, Prague
Areas of interest: nonassociative algebra, quasigroups and loops, combinatorics, computational geometry

Mei Yin
Assistant Professor
PhD, University of Arizona
Areas of interest: phase transitions, random graphs, spectral theory

Richard N. Ball
Professor Emeritus
PhD, University of Wisconsin
Areas of interest: ordered algebra, general topology, topological dynamics, universal algebra

Stanley Gudder
Professor Emeritus
PhD, University of Illinois
Areas of interest: functional analysis, mathematical physics, foundations of quantum mechanics, probability theory

James N. Hagler
Professor Emeritus
PhD, University of California-Berkeley
Areas of interest: functional analysis, topological dynamics, hereditarily indecomposable continua

COURSE DESCRIPTIONS

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MATH 3000 The Real World Seminar (1 qtr. hrs.)
Lectures by alumni and others on surviving culture shock when leaving the University and entering the job world. Open to all students regardless of major. Cross-listed with COMP 3000.

MATH 3010 History of Mathematics (4 qtr. hrs.)
This course surveys major mathematical developments beginning with ancient Egyptians and Greeks and tracing the development through Hindu-Indian mathematics, Arabic mathematics, and European mathematics up to the 18th century. Prerequisite: MATH 1953 or MATH 1963.

MATH 3040 Lattices and Order (4 qtr. hrs.)
Ordered sets, lattices as relational and as algebraic structures, ideals and filters, complete lattices, distributive and modular lattices, Boolean algebras, duality for finite distributive lattices. Prerequisite: MATH 2200.

MATH 3050 Set Theory (4 qtr. hrs.)
Zermelo-Fraenkel axioms, axiom of choice, Zorn's Lemma, ordinals, cardinals, cardinal arithmetic. Prerequisite: MATH 2200.

MATH 3060 Mathematical Logic (4 qtr. hrs.)
Classical propositional calculus (deductive systems and truth-table semantics), first-order logic (axiomatization and completeness), elements of recursion theory, introduction to nonclassical logics. Prerequisite: MATH 2200.

MATH 3090 Mathematical Probability (4 qtr. hrs.)
Limit theorems for independent random variables, multivariate distributions, generating functions. Prerequisites: MATH 2080 and MATH 3080.

MATH 3151 Advanced Linear Algebra (4 qtr. hrs.)
Vector spaces, linear mappings, matrices, inner product spaces, eigenvalues and eigenvectors. Prerequisite: MATH 2060 and MATH 2200.

MATH 3161 Introduction to Real Analysis (4 qtr. hrs.)
A theoretical introduction to the foundations of calculus including sequences, limits, continuity, derivatives and Riemann integration. Prerequisites: MATH 2080 and MATH 2200.

MATH 3166 Group Theory (4 qtr. hrs.)
Groups and homomorphisms, isomorphism theorems, symmetric groups and G-sets, the Sylow theorems, normal series, fundamental theorem of finitely generated abelian groups. Prerequisite: MATH 3170.

MATH 3170 Introduction to Abstract Algebra (4 qtr. hrs.)
Examples of groups, permutations, subgroups, cosets, Lagrange theorem, normal subgroups, factor groups, homomorphisms, isomorphisms, rings, integral domains, quaternions, rings of polynomials, Euclid algorithm, ideals, factor rings, maximal ideals, principal ideals, fields, construction of finite fields. Prerequisite: MATH 2060 and MATH 2200.

MATH 3260 Metric Spaces (4 qtr. hrs.)
Metric spaces and continuous functions; completeness and compactness; examples including norm spaces; pointwise and uniform convergence; Baire Category Theorem. Prerequisite: MATH 3161 or equivalent.

MATH 3311 Linear Programming (4 qtr. hrs.)
Linear optimization models, simplex algorithm, sensitivity analysis and duality, network models, dynamic programming, applications to physical, social and management sciences. Prerequisite: MATH 2060.

MATH 3312 Markov Chains (4 qtr. hrs.)
Discrete-time and continuous Markov Chains, ergodic theorems, random processes, elementary queueing theory, applications. Prerequisite: MATH 2060 and MATH 3080.

MATH 3400 Introduction to Geometry (4 qtr. hrs.)
Specific geometrical systems including finite, Euclidean, non-Euclidean and projective geometries. Prerequisite: MATH 2200.

MATH 3451 Chaos, Dynamics & Fractals (4 qtr. hrs.)
Introduction to one-dimensional dynamical systems, fractals; fixed and periodic points; sources and sinks; period doubling and tangent node bifurcations; chaotic dynamical systems; Sarkovskii's Theorem. Prerequisite: MATH 3161.

MATH 3550 Introduction to Theory of Numbers (4 qtr. hrs.)
Concepts of nonanalytic number theory and its history; prime numbers, divisibility, continued fractions, modular arithmetic, Diophantine equations and unsolved conjectures. Prerequisites: MATH 2200.

MATH 3651 Ordinary Differential Equations (4 qtr. hrs.)
Modeling of phenomena by ordinary differential equations; techniques of analysis and solution of such equations; oscillation theory and boundary value problems, power series methods, special functions, Laplace transforms and difference equations. Prerequisites: MATH 2060 and MATH 2070.

Course Descriptions (Continued)

MATH 3661 Partial Differential Equations (4 qtr. hrs.)
First and second order linear equations, Fourier series, the wave equation, the Cauchy problem, the heat equation, maximum principles, Laplace's equation, Green's functions. Prerequisites: MATH 2070 and MATH 2080.

MATH 3701 Combinatorics (4 qtr. hrs.)
The principle of inclusion and exclusion, elementary counting techniques, systems of distinct representatives, partitions, recursion and generating functions, Latin squares, designs and projective planes. Prerequisite: MATH 2200.

MATH 3705 Topics in Mathematics (4 qtr. hrs.)
Varying selected advanced topics in mathematics, depending on student demand and instructor interest.

MATH 3710 Graph Theory (4 qtr. hrs.)
Paths, cycles, trees, Euler tours and Hamilton cycles, bipartite graphs, matchings, basic connectivity theorems, planar graphs, Kuratowski's theorem, chromatic number, n-color theorems, introduction to Ramsey theory. Prerequisite: MATH 2200.

MATH 3720 Coding Theory (4 qtr. hrs.)
Goals of coding theory and information theory, instantaneous and Huffman codes, Shannon theorems, block and linear codes, generating and parity-check matrices, Hamming codes, perfect codes, binary Golay code, Reed-Muller codes, cyclic codes, BCH codes, Reed-Solomon codes, ideas of convolutional and turbo codes. Prerequisite: MATH 3170.

MATH 3851 Functions Complex Variable (4 qtr. hrs.)
Complex numbers, analytic functions, complex integration, series expansions, residue theory, conformal maps, advanced topics and applications. Prerequisites: MATH 2060 and MATH 2080 and MATH 2200.

MATH 3991 Independent Study (1 to 10 qtr. hrs.)
Cannot be arranged for any course that appears in regular course schedule for that particular year.

MATH 3992 Directed Study (1 to 10 qtr. hrs.)

MATH 3998 Study Abroad Resident Credit (0 to 18 qtr. hrs.)

MATH 4050 Combinatorial Set Theory (4 qtr. hrs.)
Beginning with a quick review of ZFC, the standard axioms of set theory, the course covers advanced ordinal and cardinal arithmetic and infinitary combinatorics, including Ramsey theory. Additional axioms such as the Continuum Hypothesis, Martin's Axiom, and combinatorial principles such as Diamond and their consequences for mathematics are studied. Prerequisite: MATH 3050.

MATH 4060 Descriptive Set Theory (4 qtr. hrs.)
Descriptive Set Theory is one of the main branches of modern set theory. Set theory provides techniques for the precise study of real analysis. This course covers trees as tools for analyzing sets of real numbers, Polish spaces, the Borel hierarchy, Baire-measurability, extensions of continuous functions, separation theorems, and more. Prerequisite: MATH 3050.

MATH 4070 Proof Theory (4 qtr. hrs.)
Hilbert-style systems, Natural deduction, (simply typed) lambda calculus, combinatory logic, the Curry-Howard correspondence, normalization, cartesian cloased categories, Sequent calculi, cut elimination and applications, structural rules; logical systems: classical, intuitionistic, relevance, linear; algebraic semantics. Prerequisite: MATH 2200

MATH 4080 Algebraic Logic (4 qtr. hrs.)
Elements of universal algebra, lattice theory and first-order logic; elements of abstract algebraic logic (deductive systems, algebraization, deduction filters, deduction theorems, matrix semantics); sequent calculi for substructural logics, residuated lattices, structure theory for congruencies and deductive filters; subvariety lattices (atomic varieties, axiomatizations of joins, translations); algebraic cut elimination; (un)decidability and finite model property. Prerequisites: MATH 3170 and either MATH 3040 or MATH 3060.

MATH 4110 Topology (4 qtr. hrs.)
Point set topology including topological spaces, connectedness, compactness and separate axioms; preparation for advanced courses in analysis. Prerequisites: MATH 3161 or equivalent.

MATH 4120 Algebraic Topology (4 qtr. hrs.)
Fundamental groups, simplicial homology, Euler characteristic classification of surfaces, manifolds. Prerequisites: MATH 3170 and MATH 3110/4110.

MATH 4162 Rings and Modules (4 qtr. hrs.)
Ideals, left and right R-modules, simple modules, totally decomposable modules, Wedderburn-Artin theorems, Artinian and Noetherian rings and modules, Hopkins theorem, Hilbert basis theorem, free modules, projective and injective modules, Kaplanski theorem. Prerequisites: MATH 3176 or MATH 4176.

MATH 4163 Universal Algebra (4 qtr. hrs.)
Universal algebras, congruences, lattices, distributive lattices, modular lattices, Boolean algebras, subdirectly irreducible algebras, Mal'cev theorems, varieties, Birkhoff theorem. Prerequisites: MATH 3170 and either MATH 3040 or MATH 3060.

Course Descriptions (Continued)

MATH 4164 Galois Theory (4 qtr. hrs.)
The fundamental theorem of algebra, field extensions, ruler and compass constructions, normal and separable extensions, field automorphisms, Galois correspondence, solvability and simplicity, calculating Galois groups. Prerequisite: MATH 3176/MATH 4176 and MATH 3166/MATH 4166.

MATH 4166 Group Theory (4 qtr. hrs.)
Groups and homomorphisms, isomorphism theorems, symmetric groups and G-sets, the Sylow theorems, normal series, fundamental theorem of finitely generated abelian groups. Prerequisite: MATH 3170.

MATH 4168 Lie Groups and Lie Algebras (4 qtr. hrs.)
Lie groups and Lie algebras, fundamental theorems of Lie, general structure theory; compact, nilpotent, solvable, semisimple Lie groups; classification of semisimple Lie algebras; representation theory of compact and semisimple Lie algebras and Lie groups. Additional topics as time permits: universal enveloping algebras, symmetric spaces. Prerequisites: MATH 3161 and MATH 3170.

MATH 4176 Rings and Fields (4 qtr. hrs.)
Rings, domains, fields; ideals, quotient rings, polynomials; PIDs, UFDs, Euclidean domains; maximal and prime ideals, chain conditions; extensions of fields, splitting fields, algebraic and transcendental extensions; brief introduction to Galois theory. Prerequisite: MATH 3170 or equivalent.

MATH 4181 Loop Theory (4 qtr. hrs.)
Quasigroups, loops, latin squares, 3-nets, isotopy, multiplication groups, inner mapping groups, nuclei, commutant, center, associator subloop, inverse properties, power-associative loops, Bruck loops, Bol loops, Moufang loops, octonions. Prerequisites: MATH 3166 or MATH 4166.

MATH 4260 Metric Spaces (4 qtr. hrs.)
Metric spaces and continuous functions; completeness and compactness; examples including norm spaces; pointwise and uniform convergence; Baire Category Theorem. Prerequisite: MATH 3161 or equivalent.

MATH 4270 Hilbert Spaces (4 qtr. hrs.)
Schwarz and triangle inequalities, Reisz lemma, subspaces and othogonal projections, orthonormal bases, spectrum of bounded linear operators, compact, self-adjoint, normal and unitary operators, spectral theorem and, if time permits, unbounded operators. Also, if time permits, applications to partial differential equations, physics and engineering. Prerequisite: MATH 3260/4260 or MATH 3110/4110.

MATH 4280 Measure Theory and Applications (4 qtr. hrs.)
Definition of Measure spaces; Lebesgue measure; limit theorems; Radon-Nikodym Theorem; introduction to L_p spaces. Prerequisite: MATH 3260/4260 or MATH 3110/4110.

MATH 4290 Dynamical Systems (4 qtr. hrs.)
Topological and measure theoretic dynamical systems; properties and invariants of systems; symbolic dynamics; Ergodic Theorems; applications. Prerequisites: MATH 3110/4110 or MATH 3260/4260.

MATH 4300 Graduate Seminar (1 to 4 qtr. hrs.)
Students research a topic of their choosing with the aid of a faculty member, and then prepare and present a formal lecture on the subject. Prerequisite: graduate standing or consent of the instructor.

MATH 4400 Differential Geometry (4 qtr. hrs.)
Planar and spatial curves, global properties of curves, surfaces in three dimensions, the first fundamental form, curvature of surfaces, Gaussian curvatures, geodesics, Theorema Egregium, hyperbolic geometry. Prerequisites: MATH 3170 and either MATH 3110/4110 or MATH 3260/4260.

MATH 4501 Functional Analysis (4 qtr. hrs.)
Advanced topics in structure of linear spaces; Banach spaces; Hahn-Banach Theorem and Duality; Uniform Boundedness Theorem; Open Mapping and Closed Graph Theorems; Stone-Weierstrass Theorem; Topics in Hilbert Spaces. Prerequisite: MATH 4280.

MATH 4700 Special Topics in Mathematics (1 to 4 qtr. hrs.)

MATH 4701 Combinatorial Algorithms (4 qtr. hrs.)
Basic enumeration techniques; representations of combinatorial objects; algorithms for searching, sorting, generating combinatorial objects, graph algorithms. Prerequisites: MATH 3701 or MATH 3710.

MATH 4705 Special Topics Applied Math (1 to 5 qtr. hrs.)
varying selected advanced topics in mathematics, depending on student demand. Possible alternatives include of variations, partail differential equations, algebraic topology, differential manifolds, special functions.

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Course Descriptions (Continued)

MATH 4991 Independent Study (1 to 10 qtr. hrs.)
Cannot be arranged for any course that appears in course schedule for that particular year.

MATH 4992 Directed Study (1 to 10 qtr. hrs.)

MATH 4995 Independent Research (1 to 10 qtr. hrs.)
Research projects undertaken in conjunction with a faculty member.

MATH 5000 Doctoral Seminar (3 qtr. hrs.)
Techniques, methods used in mathematical, computing research. Includes proofs, bibliographic searching, writing styles, what constitutes an acceptable dissertation.

MATH 5991 Independent Study (1 to 10 qtr. hrs.)
Cannot be arranged for any course that appears in the regular course schedule for that particular year.

MATH 5995 Independent Research (1 to 10 qtr. hrs.)
Research leading to a dissertation.

For More Information

A complete description of the program's official offerings and requirements is available from the department at http://www.du.edu/nsm/departments/mathematics/.