**MTSE 6900-MTSE 6910. Special Problems.** 1–3 hours each. Special problems in experimental or theoretical for advanced materials science graduate students. Problem chosen by the student with the approval of the supervising professor.

**MTSE 6940. Individual Research.** 1–3 hours. To be scheduled by the doctoral candidate engaged in research. May be repeated for credit.

**MTSE 6950. Doctoral Dissertation.** 3, 6 or 9 hours. To be scheduled only with consent of department. 12 hours credit required. No credit assigned until dissertation has been completed and filed with the graduate dean. Doctoral students must maintain continuous enrollment in this course subsequent to passing qualifying examination for admission to candidacy. May be repeated for credit.

**MTSE 6970. Seminar for Doctoral Candidates.** 3 hours. Demonstration of competence in a specific area of materials science as evidenced by criteria established by the faculty of each discipline. May be repeated for credit.

**MTSE 6990. Postdoctoral Research.** 3 hours. For postdoctoral fellows to further training and research experience in developing and solving problems independently. Prerequisite(s): consent of department. May be repeated for credit.

## Mathematics

The content of courses will vary from time to time, reflecting current trends and recent developments.

### *Mathematics, MATH*

**MATH 5000. Instructional Issues for the Professional Mathematician.** 3 hours. Focus on various instructional issues from the perspective of the professional mathematician. Some major topics include course planning, the content of a course syllabus, lecture styles, the preparation and mechanics of lectures, the conduct of problem solving sessions, classroom management, the student-instructor relationship, examination formats, the preparation, administration and grading of examinations and the management of teaching assistants and graders. Prerequisite(s): consent of department.

**MATH 5010-MATH 5020. Mathematical Logic and Set Theory.** 3 hours each. Rigorous development of first-order logic, basic model theory, completeness and incompleteness theorems, decidable and undecidable theories, axioms of set theory, ordinal and cardinal numbers, the axiom of choice, the continuum hypothesis, constructible sets, and basic descriptive set theory.

**MATH 5050. Linear Programming.** 3 hours. Convex polyhedra, simplex method, duality theory, network flows, integer programming, ellipsoidal method, applications to modeling and game theory. Prerequisite(s): consent of department.

**MATH 5110-MATH 5120. Introduction to Analysis.** 3 hours each. A rigorous development for the real case of the theories of continuous functions, differentiation, Riemann integration, infinite sequences and series, uniform convergence and related topics; an introduction to the complex case.

**MATH 5200. Topics in Dynamical Systems.** 3 hours. Dynamical systems in one and higher dimensions. Linearization of hyperbolic fixed points. Hamiltonian systems and twist maps. The concept of topological conjugacy and structural stability. Anosov diffeomorphisms, geodesic flow and attractors. Chaotic long-term behavior of these hyperbolic systems. Measures of complexity. Prerequisite(s): consent of department.

**MATH 5210-MATH 5220. Numerical Analysis.** 3 hours each. A rigorous mathematical analysis of numerical methods: norms, error analysis, linear systems, eigenvalues and eigenvectors, iterative methods of solving non-linear systems, polynomial and spline approximation, numerical differentiation and integration, numerical solution or ordinary and partial differential equations. Prerequisite(s): FORTRAN programming or consent of department.

**MATH 5290. Numerical Methods.** 3 hours. A non-theoretical development of various numerical methods for use with a computer to solve equations, solve linear and non-linear systems of equations, find eigenvalues and eigenvectors, approximate functions, approximate derivatives and definite integrals, solve differential equations and solve other such problems of a mathematical nature. Errors due to instability of method and those due to the finite-precision computer will be studied. Prerequisite(s): a programming language and consent of department.

**MATH 5310-MATH 5320. Functions of a Real Variable.** 3 hours each.

**MATH 5310.** Sets and operations; descriptive set properties; cardinal numbers; order types and ordinals; metric spaces; the theory of Lebesque measure; metric properties of sets.

**MATH 5320.** Set functions and abstract measure; measurable functions; types of continuity; classification of functions; the Lebesque integral; Dini derivatives and the fundamental theorem of the calculus.

**MATH 5350. Markov Processes.** 3 hours. The ergodic theorem; regular and ergodic Markov chains; absorbing chains and random walks; mean first passage time; applications to electric circuits, entropy, genetics, games, decision theory and probability.

**MATH 5400. Introduction to Functions of a Complex Variable.** 3 hours. Algebra of complex numbers and geometric representation; analytical functions; elementary functions and mapping; real-line integrals; complex integration; power series; residues, poles, conformal mapping and applications. Only one course, MATH 5400, MATH 5500 or MATH 5600, may be used towards satisfying the course work requirements for a graduate degree in mathematics.

**MATH 5410-MATH 5420. Functions of a Complex Variable.** 3 hours each. The theory of analytic functions from the Cauchy-Riemann and Weierstrass points of view.

**MATH 5450. Calculus on Manifolds.** 3 hours. Introduction to differential geometry and topology. Topics include implicit and inverse function theorems, differentiable manifolds, tangent bundles, Riemannian manifolds, tensors, curvature, differential forms, integration on manifolds and Stokes' theorem. Prerequisite(s): consent of department.

**MATH 5460-MATH 5470. Differential Equations.** 3 hours each. Calculation of solutions to systems of ordinary differential equations, study of algebraic and qualitative properties of solutions, study of partial differential equations of mathematical physics, iterative methods for numerical solutions of ordinary and partial differential equations and introduction to the finite element method. Prerequisite(s): MATH 5110-5120 and linear algebra.

**MATH 5500. Introduction to the Theory of Matrices.** 3 hours. Congruence (Hermitian); similarity; orthogonality, matrices with polynomial elements and minimal polynomials; Cayley-Hamilton theorem; bilinear and quadratic forms; eigenvalues. Only one course, MATH 5400, MATH 5500 or MATH 5600, may be used towards satisfying the course work requirements for a graduate degree in mathematics.

**MATH 5520. Modern Algebra.** 3 hours. Groups and their generalizations; homomorphism and isomorphism theories; direct sums and products; orderings; abelian groups and their invariants. Prerequisite(s): MATH 3510 or equivalent.

**MATH 5530. Selected Topics in Modern Algebra.** 3 hours. Ring and field extensions, Galois groups, ideals and valuation theory.

**MATH 5600. Introduction to Topology.** 3 hours. Point set topology; connectedness, compactness, continuous functions and metric spaces. Only one course, MATH 5400, MATH 5500 or MATH 5600, may be used towards satisfying the course work requirement for a graduate degree in mathematics.

**MATH 5610-MATH 5620. Topology.** 3 hours each. A rigorous development of abstract topological spaces, mappings, metric spaces, continua, product and quotient spaces; introduction to algebraic methods.

**MATH 5700. Selected Topics in Contemporary Mathematics.** 3 hours. Topics of current interest that vary from year to year. Prerequisite(s): consent of department. May be repeated for credit as topics vary.

**MATH 5810-MATH 5820. Probability and Statistics.** 3 hours each.

**MATH 5810.** Important densities and stochastic processes; measure and integration; laws of large numbers; limit theorems.

**MATH 5820.** Markov processes and random walks; renewal theory and Laplace transforms; characteristic functions; infinitely divisible distribution; harmonic analysis.

**MATH 5900-MATH 5910. Special Problems.** 1–3 hours each.

**MATH 5940. Seminar in Mathematical Literature.** 1–3 hours.

**MATH 5950. Master's Thesis.** 3 or 6 hours. To be scheduled only with consent of department. 6 hours credit required. No credit assigned until thesis has been completed and filed with the graduate dean. Continuous enrollment required once work on thesis has begun. May be repeated for credit.

**MATH 6010. Topics in Logic and Foundations.** 3 hours. Mathematical logic, metamathematics and foundations of mathematics. May be repeated for credit.

**MATH 6110. Topics in Analysis.** 3 hours. Measure and integration theory, summability, complex variables and functional analysis. May be repeated for credit.

**MATH 6130. Infinite Processes.** 3 hours. Topics selected from infinite series, infinite matrices, continued fractions, summation processes and integration theory.

**MATH 6150. Functional Analysis.** 3 hours. Normed linear spaces; completeness, convexity and duality. Topics selected from linear operators, spectral analysis, vector lattices and Banach algebras. May be repeated for credit.

**MATH 6170. Differential Equations.** 3 hours. Existence, uniqueness and approximation of solutions to linear and non-linear ordinary, partial and functional differential equations. Relationships with functional analysis. Emphasis is on computer-related methods. May be repeated for credit.

**MATH 6200. Topics in Ergodic Theory.** 3 hours. Basic ergodic theorems. Mixing properties and entropy. Oseledec's multiplicative ergodic theorem and Lyapunov exponents. Applications to dynamical systems. Rational functions and Julia sets. Wandering across Mandelbrot set. Sullivan's conformal measure. Thermodynamical formalism and conformal measures applied to compute Hausdorff measures and packing measures of attractors, repellors and Julia sets. Dimension invariants (Hausdorff, box and packing dimension) of these sets. Prerequisite(s): consent of department. May be repeated for credit.

**MATH 6310. Topics in Combinatorics.** 3 hours. Selected topics of current interest in combinatorics such as enumeration, combinatorial optimization, Ramsey theory, topological graph theory, random methods in combinatorics (random graphs, random matrices, randomized algorithms, etc.), combinatorial designs, matroids, formal languages and combinatorics on words, combinatorial number theory, combinatorial and symbolic methods in dynamical systems. May be repeated for credit.

**MATH 6510. Topics in Algebra.** 3 hours. Groups, rings, modules, fields and other algebraic structures; homological and categorical algebra. Multiplicative and additive number theory, diophantine equations and algebraic number theory. May be repeated for credit.

**MATH 6610. Topics in Topology and Geometry.** 3 hours. Point set and general topology, differential geometry and global geometry. May be repeated for credit.

**MATH 6620. Algebraic Topology.** 3 hours. Topics from algebraic topology such as fundamental group, singular homology, fixed point theorems, cohomology, cup products, Steenrod powers, vector bundles, classifying spaces, characteristic classes and spectral sequences. Prerequisite(s): MATH 5530 and MATH 5620. May be repeated for credit.

**MATH 6700. Selected Topics in Advanced Mathematics.** 3 hours. Topics of current interest that vary from year to year. Prerequisite(s): consent of department. May be repeated for credit as topics vary.

**MATH 6710. Topics in Applied Mathematics.** 3 hours. Optimization and control theory, perturbation methods, eigenvalue problems, generalized functions, transform methods and spectral theory. May be repeated for credit.

**MATH 6810. Probability.** 3 hours. Probability measures and integration, random variables and distributions, convergence theorems, conditional probability and expectation, martingales, stochastic processes. May be repeated for credit.

**MATH 6900-MATH 6910. Special Problems.** 1–3 hours each.

**MATH 6940. Individual Research.** Variable credit. To be scheduled by the doctoral candidate engaged in research. May be repeated for credit.

**MATH 6950. Doctoral Dissertation.** 3, 6 or 9 hours. To be scheduled only with consent of department. 12 hours credit required. No credit assigned until dissertation has been completed and filed with the graduate dean. Doctoral students must maintain continuous enrollment in this course subsequent to passing qualifying examination for admission to candidacy. May be repeated for credit.

# Mechanical and Energy Engineering

### *Mechanical and Energy Engineering , MEEN*

**MEEN 5110. Alternative Energy.** 3 hours. Introduction to the physics, systems and methods of energy conversion from non-conventional energy sources, such as solar, geothermal, ocean-thermal, biomass, tidal, hydroelectric, wind and wave energy. Advantages and disadvantages of alternative energy sources and engineering challenges for the harnessing of such forms of energy; energy storage; fuel cells.

**MEEN 5112. Nuclear Energy.** 3 hours. Atomic physics and the structure of the atom; radioactivity; interactions of neutrons with matter; nuclear cross-sections; nuclear fuels and fuel elements; elements of nuclear reactors; components and operation of nuclear power plants. Notable accidents of nuclear reactors. Breeder reactors.

**MEEN 5140. Advanced Mathematical Methods for Engineers.** 3 hours. Provides an introduction to advanced mathematical methods used in engineering science, such as vector calculus, integral transforms, partial differential equations and numerical methods.

**MEEN 5200. Principles of HVAC.** 3 hours. Thermodynamics and psychometrics applied to the HVAC system calculations, energy estimating methods, ducts and piping systems, heat pump and heat recovery systems, air-processing, refrigeration and heating equipment.

**MEEN 5210. Solar Energy.** 3 hours. Fundamentals of radiation processes, blackbody and gray-body; and gray-body radiation; solar radiation flat-plate and parabolic collectors; concentration optics and practical solar concentration devices; central receivers, solar ponds, power cycles of solar plants; thermal storage subsystems and system design.

**MEEN 5220. Computational Fluid Dynamics and Heat Transfer.** 3 hours. Finite difference, finite volume, and finite element computational methods; techniques for building geometry and meshing; commercial software; modeling and numerically solving real-world fluid flow and heat transfer problems. Prerequisite(s): MEEN 3120, MEEN 3210.

**MEEN 5300. Advanced Thermodynamics.** 3 hours. Axiomatic presentation of the law of thermodynamics including corollaries and applications related to energy conversion, the exergy method and entropy dissipation method for the evaluation of thermodynamic systems and cycles, thermodynamic equilibrium and stability, irreversible thermodynamics, chemical equilibria and applications in combustion.

**MEEN 5310. Conduction and Radiation Heat Transfer.** 3 hours. Includes heat conduction for 1-, 2- and 3-dimensional systems; separation of variables; Duhamel's theorem; Green's function; Laplace transforms; radiative properties of particulate media, semi-transparent media, and 1-dimensional gray media; and integro-differential equations. Prerequisite(s): consent of department.

**MEEN 5311. Convection Heat Transfer II.** 3 hours. Explores fundamental equations of fluid flow and heat transfer; internal and external heat transfer; laminar and turbulent heat transfer; similarity solutions; integral method; and boundary layer equations. Prerequisite(s): consent of department.

**MEEN 5315. Nanoscale Energy Transport.** 3 hours. Explores microscopic heat carriers and transport; material waves; energy states in solids; statistical description of thermodynamics; waves; particle transport process; semiconductor materials; and interfacial phenomena for non-coventional liquids. Prerequisite(s): consent of department.

**MEEN 5320. Biofluid Dynamics.** 3 hours. Review of basic fluid mechanics and heat and mass transfer; blood rheology; basic physiology as it relates to biotransport phenomena; and circulatory and respiratory systems. Prerequisite(s): consent of department.

**MEEN 5330. Combustion Science and Engineering.** 3 hours. Examines fuels and combustion; combustion stoichiometry; chemical equilibrium; adiabatic flame temperature; reaction kinetics; transport processes; conservation laws; ignition processes; gas flames classification; premixed flames; laminar and turbulent regimes; flame propagation; deflagrations and detonations; diffusion flames; pollutant formation; atmospheric impacts; engine combustion; solid phase combustion; combustion diagnostics; and combustion applications. Prerequisite(s): MEEN 3110 or consent of department.

**MEEN 5340. Advanced Fluid Mechanics.** 3 hours. Fundamentals of vector and tensor notation and formulation of governing equations; model of inviscid and viscous flow, vorticity and circulation; exact solutions; turbulence; boundary layer theory; free surface flow. Prerequisite(s): consent of department.

**MEEN 5350. Dispersed Multiphase Flow and Heat Transfer.** 3 hours. Characteristics of particles, bubbles and drops; conservation equations, creeping flow solution, flow and heat transfer at higher Reynolds numbers; the treatment of non-spherical particles, bubbles, and drops; effects of rotation and shear; two-way effects of turbulence; effects of higher concentration, molecular and statistical description.

**MEEN 5351. Multiphase Flow Modeling.** 3 hours. Covers a broad spectrum of numerical techniques for multiphase flow modeling, ranging from the continuum fluid model to discrete particle method. Examines the fundamentals of multiphase flows, including motion of a single particle in a viscous fluid, particle fluidization, and flow in porous media. Prerequisite(s): consent of department.

**MEEN 5410. Introduction to Solid Mechanics.** 3 hours. Explores tensor analysis; kinematics and kinetics of motion; material constitutive law; 2- and 3-dimensional stress analysis; stress concentration; fracture mechanics; contact mechanics; plates and shells; finite element methods; and wave propagation. Prerequisite(s): consent of department.

**MEEN 5420. Continuum Mechanics.** 3 hours. Describes the fundamental law of physics applicable to a continuous medium and develops the linear theory. Introduces Cartesian tensors, state of stress, kinematics of deformation, and constitutive equations of mechanics and thermodynamics. Prerequisite(s): consent of department.