MATERIALS SCIENCE

http://www.uvm.edu/matsci/

OVERVIEW

UVM’s graduate program in Materials Science is engaged in interdisciplinary education and research on the fundamental physical, chemical, electrical and mechanical properties and applications of materials. Our internationally-recognized faculty and graduate students focus on a variety of theoretical and experimental research topics ranging from electronic materials to bio-polymers. Current interests include nanomechanics, graphene and quantum magnetism, dynamics of quantum systems, spin-dependent phenomena in semiconductors, real-time x-ray scattering and thin film microfabrication, synthesis of novel organometalics and small molecule semiconductors, supramolecular nanomaterials, computational multiscale modeling of complex materials, as well as materials for biomedical applications. Experimental and computational on-campus facilities include state-of-the-art transport, microscopy, spectroscopy (optical and X-ray) characterization and a supercomputing center. Our experimental faculty and graduate students work in close collaboration with scientists from national laboratories such as the Brookhaven National Lab and the National High Magnetic Field Lab.

We offer students the opportunity to follow customized curricula organized in 3 tracks (Electronic Materials, Biomaterials and Mechanics of Materials) that prepares them to be successful in their chosen research area. Research and teaching graduate assistantships are available for full-time students on a competitive basis and the program also welcomes self–supporting part-time students in partnership with industry.

DEGREES

- Materials Science AMP (http://catalogue.uvm.edu/graduate/materials/materialssciencesamp/)
- Materials Science M.S. (http://catalogue.uvm.edu/graduate/materials/materialssciencesms/)
- Materials Science Ph.D. (http://catalogue.uvm.edu/graduate/materials/materialssciencedph/)

FACULTY

Badireddy, Appala Raju; Assistant Professor, Department of Civil and Environmental Engineering; PHD, University of Houston
Clougherty, Dennis Paul; Professor, Department of Physics; PHD, Massachusetts Institute of Technology
Doiron, Amber L.; Assistant Professor; Department of Electrical and Biomedical Engineering; PHD, University of Texas Austin
Dubief, Yves C.; Associate Professor Department of Mechanical Engineering; PHD, Institut National Polytechnique de Grenoble
Fletcher, Douglas G.; Professor, Department of Mechanical Engineering; PHD, University of Virginia
Floreani, Rachael Ann; Associate Professor, Department of Mechanical Engineering; PHD, Colorado State University
Furis, Madalina Ioana; Adjunct Professor, Department of Physics; PHD, University of Buffalo
Headrick, Randall L.; Professor, Department of Physics; PHD, University of Pennsylvania
Kotov, Valeri N.; Professor, Department of Physics; PHD, Clarkson University
Landry, Christopher C.; Professor, Department of Chemistry; PHD, Harvard University
Li, Jianing; Associate Professor, Department of Chemistry; PHD, Columbia University
Li, Wei; Assistant Professor, Department of Mechanical Engineering, PHD, Michigan State University
Ma, Jihong; Assistant Professor, Department of Mechanical Engineering, PHD, University of Minnesota, Twin Cities
Punihaoale, David; Assistant Professor, Department of Chemistry, PHD, University of Pittsburgh
Ruggiero, Michael; Assistant Professor, Department of Chemistry; PHD, Syracuse University
Sansoz, Frederic P.; Professor, Department of Mechanical Engineering; PHD, Ecole Des Mines de Paris
Schadler, Linda S.; Dean, College of Engineering and Mathematical Sciences; Professor, Department of Mechanical Engineering; PHD, University of Pennsylvania
Schneebeli, Severin; Associate Professor, Department of Chemistry; PHD, Columbia University
Vanegas, Juan; Assistant Professor, Department of Physics, PHD; University of California Davis
Waterman, Rory; Professor, Department of Chemistry; PHD, University of Chicago
White, Matthew S.; Associate Professor, Department of Physics; PHD; University of Colorado Boulder
Xia, Tian; Professor, Department of Electrical and Biomedical Engineering; PHD, University of Rhode Island

Chemistry Courses

CHEM 205. Biochemistry I. 3 Credits.
Introduction to chemistry and structure of biological macromolecules; examination of mechanisms of chemical processes in biological systems including enzyme catalysis, biosynthesis, regulation, and information transfer. Prerequisite: CHEM 048 or CHEM 142 or CHEM 144. Cross-listed with: BIOC 205 and MMG 205.

CHEM 206. Biochemistry II. 3 Credits.
Continuation of Biochemistry I. Biochemistry of nucleic acids; nucleic acid based processes, such as replication and transcription; cellular information transfer, genomics, and proteomics. Prerequisite: BIOC 205, CHEM 205, or MMG 205. Cross-listed with: BIOC 206 and MMG 206.
CHEM 207. Biochemistry Lab. 3 Credits.
Introduction to biochemical tools, including spectrometry, chromatography, and electrophoresis; natural and recombinant enzyme isolation; assays of DNA-modifying enzymes; computer-based structure/function exercises. Prerequisite: BIOC 205, CHEM 205, or MMG 205. Cross-listed with: BIOC 207 and MMG 207.

CHEM 214. Polymer Chemistry. 3 Credits.
Polymer synthesis and characterization. Kinetic models for polymerization and copolymerization. Physical properties, characterization of polymers in the solid state and in solution. Prerequisite: CHEM 048 or CHEM 142 or CHEM 144, and CHEM 165.

CHEM 221. Instrumental Analysis. 3 Credits.
Systematic survey of modern methods of chemical analysis. Fundamental principles and applications of spectroscopy, electrochemistry, and separation techniques. Prerequisite: CHEM 121. Credit for or concurrent enrollment in CHEM 165 strongly recommended.

CHEM 226. Analytical Spectroscopy. 3 Credits.

CHEM 231. Advanced Inorganic Chemistry. 3 Credits.
Molecular symmetry and group theory with an emphasis on applications (vibrational and electronic spectra, bonding and reactivity); introduction to transition metal processes; bioinorganic chemistry. Prerequisite: CHEM 165; CHEM 047, CHEM 141, or CHEM 143.

CHEM 234. Organometallic Chemistry. 3 Credits.
Synthesis, structure, bonding, properties, reactions, and applications of organometallic systems; mechanisms of organometallic reactions including oxidative addition and insertion reactions with applications in catalysis. Prerequisite: CHEM 131 or CHEM 231.

CHEM 236. Physical Inorganic Chemistry. 3 Credits.
Determination of molecular and electronic structure of inorganic complexes using spectroscopic techniques. Introduction to magnetism. Interpretation of spectroscopic data within the frameworks of group theory and electronic structure calculations. Prerequisites: CHEM 131 and CHEM 165; or CHEM 231.

CHEM 241. Advanced Organic Chemistry 1. 3 Credits.
Stereochemistry, conformational analysis, stereoelectronic effects, transition state theory, molecular orbital theory, and reactivity criteria are discussed in regards to reaction mechanisms and functional group manipulations. Prerequisite: CHEM 142 or CHEM 144.

CHEM 242. Advanced Organic Chemistry 2. 3 Credits.
Modern synthetic organic methods and approaches to multi-step synthesis are discussed. Selected total syntheses are reviewed to highlight important concepts including diastereoselective and enantioselective processes. Prerequisite: CHEM 241.

CHEM 250. Analytical Chemistry. 3 Credits.
Modern synthetic organic methods and approaches to multi-step synthesis are discussed. Selected total syntheses are reviewed to highlight important concepts including diastereoselective and enantioselective processes. Prerequisite: CHEM 241.

CHEM 260. Advanced Physical Chemistry. 3 Credits.
Builds on the concepts from Introductory Physical Chemistry (CHEM 165). The three major areas of quantum chemistry, thermodynamics, and kinetics are extended in greater depth, and at a higher level of mathematical rigor. Prerequisite: CHEM 165. Corequisites: CHEM 167 or MATH 121.

CHEM 267. Topics in Physical Chemistry. 1-3 Credits.
Selected topics of current interest in physical chemistry. See Schedule of Courses for specific titles. May be repeated for credit with different content. Topics vary by offering; periodic offering at intervals that may exceed four years. Prerequisite: CHEM 260.

CHEM 274. Solid State Chemistry. 3 Credits.
Explores the rich field of solid-state chemistry. Solid-state materials represent some of the most promising advanced materials in development, with applications ranging from pharmaceuticals to flexible electronics. Introduces the chemical physics surrounding solids. Topics include (but are not limited to) crystals and their properties, nanomaterials, semiconductors, and characterization methods. Prerequisite: CHEM 165.

CHEM 275. Computational Chemistry. 3 Credits.
Explores the techniques and applications of computational chemistry to model organic, inorganic, and biological molecules. Introduces basic level of classical and quantum modeling, cheminformatics and big chemical data, as well as computer-aided design of new materials and medicines. Prerequisite: CHEM 260.

CHEM 318. Current Topics in Chemistry. 0 or 1 Credits.
Survey of current topics in the chemistry literature. May be repeated for credit with different content. Prerequisite: Graduate Chemistry students only.

CHEM 379. Intro to Graduate Research. 1 Credit.
Introduction to graduate research in chemistry. Overview of faculty research areas and department/university research resources. Prerequisites: Chemistry graduate students only.

CHEM 380. Chemical Investigations. 1 Credit.
Current problems and literature.

CHEM 381. Grad Seminar. 1 Credit.
Current problems and literature.

CHEM 384. Advanced Topics in Chemistry. 2 Credits.
Comprehensive independent study in chemistry.

CHEM 390. Internship. 1-18 Credits.
On-site supervised work experience combined with a structured academic learning plan directed by a faculty member or a faculty-staff team in which a faculty member is the instructor of record, for which academic credit is awarded. Offered at department discretion.

CHEM 391. Master’s Thesis Research. 1-18 Credits.

CHEM 392. Independent Study. 1-18 Credits.
A course which is tailored to fit the interests of a specific student, which occurs outside the traditional classroom/laboratory setting under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.
CHEM 394. Independent Graduate Research. 1-18 Credits.
Graduate student work on individual or small team research projects under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

CHEM 395. Independent Lit Rsch Project. 1-12 Credits.
Reading and literature research culminating in the preparation of a comprehensive and critical review of a topic of current interest in chemistry.

CHEM 396. Advanced Special Topics. 1-18 Credits.
See Schedule of Courses for specific titles.

CHEM 484. Advanced Topics in Chemistry. 2 Credits.
Comprehensive independent study in chemistry.

CHEM 487. Research Problem Conception. 1 Credit.
Identification of a current research problem to be addressed by original, independent research. Prerequisite: CHEM 484.

CHEM 488. Research Problem Solution. 1 Credit.
Solution to a current research problem to be addressed by original, independent research. Prerequisite: CHEM 487.

CHEM 490. Internship. 1-18 Credits.
On-site supervised work experience combined with a structured academic learning plan directed by a faculty member or a faculty-staff team in which a faculty member is the instructor of record, for which academic credit is awarded. Offered at department discretion.

CHEM 491. Doctoral Dissertation Research. 1-18 Credits.
CHEM 494. Independent Graduate Research. 1-18 Credits.
Graduate student work on individual or small team research projects under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

CHEM 496. Advanced Special Topics. 1-18 Credits.
See Schedule of Courses for specific titles.

Electrical Engineering Courses

EE 210. Control Systems. 3 Credits.
Analysis and design of continuous and discrete-time control systems; stability, signal flow, performance criteria, classical and state variable methods, simulation design tools, computer-based realizations. Credit not given for more than one of the courses EE 110, EE 210. Prerequisite: EE 171 or ME 111. Cross-listed with: ME 210.

EE 211. Real-Time Control Systems. 3 Credits.
Digital control systems analysis and design. Topics include: difference equations, the Z-transforms, discrete-time transfer functions, state-space models, sampled-data systems, discretization, real-time control, microprocessor implementation, and optimal control. Project-based final. Prerequisites: (C+ or better in EE 110 or EE 210 or ME 210) and (EE 134 or a B- or better in EE 101).

EE 215. Electric Energy Systems Analys. 3 Credits.
Transmission line, generator, transformer modeling and control, per-unit conversion, power flow calculations and software, symmetric components and fault analysis, protection/relaying, stability analysis, smart grid. Prerequisite: EE 113. Co-requisite: MATH 122 (preferred) or MATH 124.

EE 217. Smart Grid. 3 Credits.
Smart Grid: Using information/communication technology to modernize electric power/energy systems, including generation, transmission, distribution and consumption. Electricity physics/economics/policy; renewable energy; energy storage; demand response; energy efficiency; distributed generation; advanced metering infrastructure; distribution automation; microgrids; synchrophasors; HVDC and FACTS systems. Prerequisite: EE 113 or Graduate standing. Co-requisite: EE 215 recommended.

EE 218. Power Electronics. 3 Credits.
An introduction to the field of power conversion using power electronics devices. Topics include Energy and Power, AC-to-DC Converters, DC-to-DC Converters, DC-to-AC Converters, Elements of Control and Design of Power Converters, Applications of Power Electronics in Renewable Energy and Microgrids. Simulations and experiments illustrate concepts. Final project related to renewable energy. Prerequisites: EE 120 or Graduate student standing.

EE 221. Digital VLSI Circuit Design. 0 or 3 Credits.
Design of VLSI circuits using a modular approach with industrial grade software: schematic capture; circuit design languages (HDL); full-custom layouts; mixed signals; synthesis. Laboratory. Prerequisites: EE 120. Pre/co-requisites: EE 131.

EE 222. Analog VLSI Circuit Design. 0 or 3 Credits.
The design, layout, and simulation of VLSI analog circuits. Emphasis on small signal models and circuits used in operational amplifiers. Prerequisites: EE 120 or Graduate student in Electrical Engineering or Physics.

EE 226. RF Circuit Design. 3 Credits.
An introduction to the design and analysis of active and passive radio frequency and microwave circuits. Topics include radio frequency and microwave circuit analysis, measurement methods, transmission line structures, matching networks, computer-aided analysis and design. Prerequisites: EE 120, EE 121.

EE 227. Biomedical Instrumentation. 3 Credits.
Measurement techniques for biomedical engineering research and industry, and health care institutions. Integrated biomedical monitoring, diagnostic, and therapeutic instrumentation. Prerequisite: EE 100 or EE 004 or EE 021 or EE 075. Co-requisites: EE 120, ANPS 020, or Instructor permission. Cross-listed with: BME 227.
EE 228. Sensors. 3 Credits.
Sensor design, interrogation, and implementation. A wide variety of electrical, electronic, optical, mechanic, and cross-disciplinary devices. System designs, measurement techniques, and methodologies. Interface electronics, system grounding and shielding methods. Prerequisite: EE 101 or EE 120.

EE 229. Biosignal Decoding. 3 Credits.
Overview of biomedical measurement techniques; development of Python software to visualize, denoise, and decode biomedical signals. Prerequisites: CS021; (BME 111 or EE 171) or (ME 111 and EE 101) or Instructor permission. Pre/Co-requisite: Beginner knowledge of Python programming is strongly suggested. Cross-listed with: BME 229.

EE 231. Digital Computer Design I. 3 Credits.
Hardware organization and realization, hard-wired and microprogrammed control units, interrupt and I/O systems. Hardware design language introduced and used for computer design. Prerequisites: EE 131; EE 134 or CS 121.

EE 261. Semiconductor Materials/Device. 3 Credits.
Energy band theory, effective mass, band structure and electronic properties of semiconductors. Transport of electrons and holes in bulk materials and across interfaces. MOSFETs, BJTs, pn junctions, and Schottky barriers. Prerequisite: EE 120 or Graduate Student standing.

EE 272. Information Theory. 3 Credits.
Introduction to probability concepts of information theory; entropy of probability models; theoretical derivations of channel capacity; coding methods and theorems, sampling theorems. Prerequisite: Graduate student standing or STAT 151.

EE 275. Digital Signal Processing. 3 Credits.
Covers principles and methods for digital signal processing. The analysis and design of discrete-time systems as signal processing devices is provided in the context of filter design and topics on image processing. Topics covered: quantization, reconstruction of signals, z-transform, FIR/IIR, intro to images, pixel and region-based classification and segmentation, among others. Prerequisite: EE 171.

EE 278. Wireless Communication. 3 Credits.
Modern wireless systems, including cellular design, propagation modeling, multiple access and equalization techniques. Pre/co-requisites: EE 174, STAT 151.

EE 279. Wireless Sensor Networks. 3 Credits.
Applications of and technologies behind wireless sensor networks. A systems-level perspective that integrates wireless networking, antennas, radio frequency circuitry, sensors, digital signal processing, embedded systems, and energy. Term project. Prerequisite: EE 171 or Instructor permission.

EE 301. System Theory. 3 Credits.

EE 302. Stochastic Processes. 3 Credits.
Probability theory, random variables and stochastic processes. Response of linear systems to random inputs. Applications in engineering. Prerequisites: EE 171 or ME 111; and STAT 151 or STAT 143.

EE 303. Convex Optimization. 3 Credits.
Provides advanced mathematical tools to recognize optimization problems from applications, presents rigorous theory of convex optimization with an emphasis on results that are helpful for implementation/computation/modeling, providing student with the experience and understanding necessary to use the tools in their own research work or applications. Prerequisites: Linear Algebra, Multivariable calculus, Graduate student standing.

EE 314. Nonlinear System Theory. 3 Credits.
Basic nonlinear methods including computational and geometrical techniques for analysis of nonlinear systems. Describing function methods and bifurcation and catastrophe theory. Sensitivity and stability considerations. Prerequisite: MATH 230 or MATH 271. Pre/Co-requisites: EE 301 recommended.

EE 371. Estimation Theory. 3 Credits.

EE 390. Internship. 1-18 Credits.
On-site supervised work experience combined with a structured academic learning plan directed by a faculty member or a faculty-staff team in which a faculty member is the instructor of record, for which academic credit is awarded. Offered at department discretion.

EE 391. Master's Thesis Research. 1-18 Credits.

EE 392. Master's Project. 1-3 Credits.
Master's Project.

EE 393. Graduate Seminar. 1 Credit.
Presentation and discussion of advanced problems, research, and current topics in Electrical Engineering by faculty, graduate students, and outside guest speakers.

EE 394. Independent Study. 1-18 Credits.
A course which is tailored to fit the interests of a specific student, which occurs outside the traditional classroom/laboratory setting under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.
EE 395. Advanced Special Topics. 1-18 Credits.  
Advanced topics of current interest in electrical engineering. 
Prerequisite: Instructor permission.  

EE 398. Independent Graduate Research. 1-18 Credits.  
Graduate student work on individual or small team research projects 
under the supervision of a faculty member, for which credit is 
awarded. Offered at department discretion.  

EE 490. Internship. 1-18 Credits.  
On-site supervised work experience combined with a structured 
academic learning plan directed by a faculty member or a faculty-staff 
team in which a faculty member is the instructor of record, for which 
academic credit is awarded. Offered at department discretion.  

EE 491. Doctoral Dissertation Research. 1-18 Credits.  
See Schedule of Courses for specific titles.  

EE 496. Advanced Special Topics. 1-18 Credits.  
See Schedule of Courses for specific titles.  

EE 498. Independent Graduate Research. 1-18 Credits.  
Graduate student work on individual or small team research projects 
under the supervision of a faculty member, for which credit is 
awarded. Offered at department discretion.  

Mathematics Courses  

MATH 230. QR: Ordinary Differential Equation. 3 Credits.  
Solutions of linear ordinary differential equations, the Laplace 
transformation, and series solutions of differential equations.  
Prerequisite: MATH 121. Corequisite: MATH 122 or MATH 124.  
Credit not granted for more than one of the courses MATH 230 or 
MATH 271.  

MATH 235. QR: Mathematical Models & Analysis. 3 Credits.  
Techniques of Calculus and linear algebra are applied for 
mathematical analysis of models of natural and human-created 
phenomena. Students are coached to give presentations.  
Prerequisites: MATH 121; MATH 122 or MATH 124 or MATH 230 
or MATH 271.  

MATH 237. QR: Intro to Numerical Analysis. 3 Credits.  
Error analysis, root-finding, interpolation, least squares, quadrature, 
linear equations, numerical solution of ordinary differential 
equations. Prerequisites: MATH 121; MATH 122 or MATH 124 or 
MATH 271; CS 020 or CS 021. Cross-listed with: CS 237.  

MATH 241. QR: Any in Several Real Vars I. 3 Credits.  
Properties of the real numbers, basic topology of metric spaces, 
infinite sequences and series, continuity. Prerequisites: MATH 141 or 
MATH 151 or C- or better in Math 052; MATH 121; MATH 122 or 
MATH 124.  

MATH 242. QR: Any in Several Real Vars II. 3 Credits.  
Differentiation and integration in n-space, uniform convergence of 
functions, fundamental theorem of calculus, inverse and implicit 
function theorems. Prerequisite: MATH 241.  

MATH 247. QR: Complex Analysis. 3 Credits.  
An introduction to the theory of analytic functions of one complex 
variable, covering the techniques of complex analysis useful in 
science and engineering as well as the theory. Topics include 
complex numbers, analytic and holomorphic functions, power and 
Laurent series expansions, and Cauchy’s theorems on integration.  
Prerequisites: MATH 052 or CS 064; MATH 121.  

MATH 251. QR: Abstract Algebra I. 3 Credits.  
Basic theory of groups, rings, fields, homomorphisms, and 
isomorphisms. Prerequisites: MATH 141 or MATH 151 or C- or 
better in MATH 052; MATH 122 or MATH 124.  

MATH 252. QR: Abstract Algebra II. 3 Credits.  
Modules, vector spaces, linear transformations, rational and Jordan 
canonical forms. Finite fields, field extensions, and Galois theory 
leading to the insolvability of quintic equations. Prerequisite: 
MATH 251.  

MATH 254. QR: Topology. 3 Credits.  
An introduction to point set topology. Topics include open and 
closed sets, continuous functions, compactness, connectedness, 
metric and Hausdorff spaces. If time permits, introduction to 
algebraic topology through topics such as the fundamental group. 
Provides background for analysis and graduate topology courses as 
well as for topological data science. Prerequisites: MATH 052 or 
CS 064; MATH 121 or MATH 122 or MATH 124.  

MATH 255. QR: Elementary Number Theory. 3 Credits.  
Divisibility, prime numbers, Diophantine equations, congruence 
of numbers, and methods of solving congruences. A significant 
portion of the course devoted to individual and/or team projects. 
Prerequisite: MATH 052; MATH 121 or MATH 122 or MATH 124.  

MATH 259. QR: Cryptography. 3 Credits.  
A survey of classical and modern cryptography. The strengths and 
weaknesses of various cryptosystems are discussed. Topics include 
specific public-key and private-key cryptosystems such as RSA, 
ElGamal, and elliptic curve cryptosystems, as well as digital signatures 
and key exchange. Prerequisite: MATH 052 or CS 064; MATH 121 or 
MATH 122 or MATH 124.  

MATH 260. QR: Foundations of Geometry. 3 Credits.  
Complex numbers as tool to solve problems in Euclidean geometry. 
Two models of hyperbolic (non-Euclidean) geometry: Poincare 
and upper-half plane. Invariants and Moebius transformations. 
Prerequisite: MATH 052 or CS 064; MATH 121, MATH 122, or 
MATH 124; or Instructor permission.  

MATH 266. QR: Chaos, Fractals & Dynamical Syst. 3 Credits.  
Discrete and continuous dynamical systems, Julia sets, the 
Mandelbrot set, period doubling, renormalization, Henon map, phase 
plane analysis and Lorenz equations. Prerequisite: MATH 122 or 
MATH 124. CS 020 or CS 021 recommended. Cross-listed with: 
CSYS 266.
MATH 268. QR:Mathematical Biology&Ecol. 3 Credits.
Mathematical modeling in the life sciences. Topics include population modeling, dynamics of infectious diseases, reaction kinetics, wave phenomena in biology, and biological pattern formation. Prerequisite: MATH 122 or MATH 124; MATH 230 or MATH 271; or Instructor permission.

MATH 271. QR:Adv Engineering Mathematics. 3 Credits.
Differential equations, Laplace transforms, and systems of differential equations; brief introduction to Fourier series. Examples from engineering and physical sciences. Credit not granted for both MATH 230 and MATH 271. No credit for Mathematics majors. Prerequisite: MATH 121. Co-requisites: Preferred: MATH 122 or MATH 124; or MATH 120.

MATH 273. QR:Combinatorial Graph Theory. 3 Credits.
Paths and trees, connectivity, Eulerian and Hamiltonian cycles, matchings, edge and vertex colorings, planar graphs, Euler's formula and the Four Color Theorem, networks. Prerequisite: MATH 052.

MATH 300. Principles of Complex Systems. 3 Credits.
Introduction to fundamental concepts of complex systems. Topics include: emergence, scaling phenomena, and mechanisms, multi-scale systems, failure, robustness, collective social phenomena, complex networks. Students from all disciplines welcomed. Pre/co-requisites: Calculus and statistics required; Linear Algebra, Differential Equations, and Computer programming recommended but not required. Cross-listed with: CSYS 300.

MATH 303. Complex Networks. 3 Credits.
Detailed exploration of distribution, transportation, small-world, scale-free, social, biological, organizational networks; generative mechanisms; measurement and statistics of network properties; network dynamics; contagion processes. Students from all disciplines welcomed. Pre/co-requisites: MATH 300/CSYS 300, Calculus, and Statistics required. Cross-listed with: CSYS 303.

MATH 330. Adv Ordinary Diff Equations. 3 Credits.
Linear and nonlinear systems, approximate solutions, existence, uniqueness, dependence on initial conditions, stability, asymptotic behavior, singularities, self-adjoint problems. Prerequisite: MATH 230.

MATH 331. Theory of Func of Complex Var. 3 Credits.
Complex functions, differentiation and the Cauchy-Riemann equations, power and Laurent series, integration, calculus of residues, contour integration, isolated singularities, conformal mapping, harmonic functions. Prerequisite: MATH 242.

MATH 333. Thy Functions Real Variables. 3 Credits.
Lebesgue measure and integration theory, Monotone and Dominated Convergence Theorems and applications, product measures, basic theory of LP-spaces. Prerequisite: MATH 242.

MATH 337. Numerical Diff Equations. 3 Credits.
Numerical solution and analysis of differential equations: initial-value and boundary-value problems; finite difference and finite element methods. Prerequisites: MATH 121; MATH 122 or MATH 124; MATH 230 or MATH 271 or MATH 237 recommended.

MATH 339. Partial Differential Equations. 3 Credits.
Classification of equations, linear equations, first order equations, second order elliptic, parabolic, and hyperbolic equations, uniqueness and existence of solutions. Prerequisite: MATH 230.

MATH 349. Nonlinear Partial Diff Eqs. 3 Credits.
This course covers modern mathematical theories and numerical methods for nonlinear partial differential equations. Topics include: inverse scattering transform; solitons; bilinear method; Darboux transformation; solitary waves; Vakhitov-Kolokolov stability criterion; transverse instability; virial theorem; wave collapse; pseudo-spectral method; split-step method. Prerequisites: MATH 330 (or equivalent) or Instructor permission.

MATH 350. Abstract Algebra III. 3 Credits.
Advanced group theory and field theory. Prerequisites: MATH 252 or Graduate standing.

MATH 351. Topics in Algebra. 3 Credits.
Topics will vary each semester and may include algebraic number theory, algebraic geometry, and the arithmetic of elliptic curves. Repeatable for credit with Instructor permission. Topics vary by offering; periodic offering at intervals that may exceed four years. Prerequisite: MATH 252.

MATH 352. Abstract Algebra IV. 3 Credits.
Ring theory and module theory at the graduate level, with emphasis on commutative algebra. Prerequisite: MATH 350.

MATH 354. Algebraic Topology. 3 Credits.
Homotopy, Seifert-van Kampen Theorem; simplicial, singular, and Čech homology. Prerequisite: MATH 241 or MATH 254.

MATH 373. Topics in Combinatorics. 3 Credits.
Topics will vary each semester and may include combinatorial designs, coding theory, topological graph theory, cryptography. Topics vary by offering; periodic offering at intervals that may exceed four years. Prerequisite: MATH 251 or MATH 273.

MATH 390. Internship. 1-18 Credits.
On-site supervised work experience combined with a structured academic learning plan directed by a faculty member or a faculty-staff team in which a faculty member is the instructor of record, for which academic credit is awarded. Offered at department discretion.

MATH 391. Master's Thesis Research. 1-18 Credits.
A course which is tailored to fit the interests of a specific student, which occurs outside the traditional classroom/laboratory setting under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

MATH 392. Independent Study. 1-18 Credits.
A course which is tailored to fit the interests of a specific student, which occurs outside the traditional classroom/laboratory setting under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

MATH 394. Independent Graduate Research. 1-18 Credits.
Graduate student work on individual or small team research projects under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

MATH 395. Advanced Special Topics. 1-18 Credits.
Subject will vary from year to year. May be repeated for credit.
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MATH 490. Internship. 1-18 Credits.
On-site supervised work experience combined with a structured academic learning plan directed by a faculty member or a faculty-staff team in which a faculty member is the instructor of record, for which academic credit is awarded. Offered at department discretion.

MATH 491. Doctoral Dissertation Research. 1-18 Credits.

MATH 494. Independent Graduate Research. 1-18 Credits.
Graduate student work on individual or small team research projects under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

MATH 496. Advanced Special Topics. 1-18 Credits.
See Schedule of Courses for specific titles.

Mechanical Engineering Courses

ME 201. Biomaterials Engineering. 3 Credits.
A materials science and engineering approach is used to explore the structure-function relationships of natural and bio-inspired materials for various engineering applications. The emphasis is on mechanical design and function. The medical applications of biomaterials will be discussed. Prerequisite: ME 101 or BME 112. Cross-listed with: BME 201.

ME 203. Machinery Analysis & Synthesis. 3 Credits.
Kinematic and kinetic analysis of two- and three-dimensional machines; kinematic synthesis, electromechanical and servo mechanisms; application to robotic mechanisms. Prerequisite: Senior standing in ME.

ME 204. Biothermodynamics. 3 Credits.
Inter-disciplinary; guides the student through the thermodynamics of living organisms, comprised of the study of energy transformation in the life sciences. Designed for students from the STEM disciplines. Covers Gibbs free energy, statistical thermodynamics, binding equilibria, and reaction kinetics. Prerequisites: ME 123, ME 124, or BME 112. Cross-listed with: BME 204.

ME 206. Biomechanics of Human Motion. 3 Credits.
Biomechanics of Human Motion will describe the typical processes from small scale protein interactions to large scale joint torques that result in human locomotion. Clinical problems and athletic performance will be discussed. Students will learn about musculoskeletal tissues related to force generation/transmission and will perform kinematic/kinetic analyses. Prerequisites: BME 011 or ME 012. Pre/Co-requisites: ME 101 or ME 111 or BME 111. Cross-listed with: BME 206.

ME 207. Intro Biomedical Engineering. 3 Credits.
Introduction to bioengineering science including biomechanics, biomaterials, biomedical imaging, rehabilitation engineering, biomedical computing, biomedical instrumentation, and transport phenomena. Prerequisite: Senior standing in all engineering majors other than Biomedical Engineering, Graduate Student standing with Instructor permission. Cross-listed with: EE 207.

ME 208. Biomechanics: Tissue Engr. 3 Credits.
Solid biomechanics including structure, function and mechanical properties of biological tissues. Tissue engineering involving cell mechanics, scaffold materials, and signaling. Current literature topics are covered. Prerequisites: ME 101 or BME 112. Cross-listed with: BME 208.

ME 210. Control Systems. 3 Credits.
Analysis and design of continuous and discrete-time control systems; stability, signal flow, performance criteria, classical and state variable methods, simulation design tools, computer-based realizations. Credit not given for more than one of the courses EE 110, ME 210. Prerequisites: EE 171 or ME 111. Cross-listed with: EE 210.

ME 218. Numerical Methods for Engineer. 3 Credits.
Foundational concepts of numerical integration, numerical differentiation, and numerical approximation and solution of differential and partial differential equations of the type encountered in the analysis of engineering problems and data processing. Prerequisites: MATH 271, CS 020; MATH 122 or MATH 124. Cross-listed with: CE 218.

ME 234. Mechanical Vibrations. 3 Credits.
Analysis, measurement, and control of mechanical vibrations; SDOF, MDOF, and rotating systems, forced, free, and random vibrations. Prerequisite: ME 111 or Senior/Graduate standing in engineering or physical sciences.

ME 236. Renewable Energy Harvesting. 3 Credits.
Covers the engineering fundamentals of different renewable energy technologies, including wind power, tidal power, solar power, biomass, hydropower, etc. Focus placed on the mathematical derivation and application of small scale vibration energy harvesting technologies. Prerequisite: ME 143 or CE 160.

ME 237. Turbulence. 3 Credits.
Description of turbulent flows; statistical and modeling of turbulent flows; Navier Stokes as a dynamical system; experimental and numerical approaches. Prerequisite: ME 143.

ME 238. Energy Systems Engineering. 3 Credits.
Engineering assessment of both potentially sustainable and unsustainable practical primary energy systems. Examination of options of meeting demand and impacts on the environment. Prerequisite: ME 042.

ME 239. Rocket Propulsion. 3 Credits.
Flight mechanics and propulsion requirements for atmospheric and space flight. Thermochemistry of fuels and propellants. Operating principles of chemical, electrical and nuclear propulsion systems. Pre/co-requisites: ME 143/ME 240 recommended or permission of the Instructor.

ME 240. Compressible Flow. 3 Credits.
Theory of compressible flow. Normal and oblique shocks; expansion waves; unsteady wave motion; method of characteristics; linearized external flows; conical and 3D flows. Prerequisite: ME 143 or equivalent.
ME 242. Adv Engr Thermodynamics I. 3 Credits.
Foundations of statistical mechanics. Gases and crystals. Chemical equilibrium. Irreversible processes. Prerequisite: Senior/Graduate standing or permission.

ME 243. Incompressible Flow. 3 Credits.
Intermediate treatment of incompressible fluid flow; Navier-Stokes equations; two-dimensional potential flows; wing theory; vorticity and vortex structures; laminar and turbulent boundary layers. Prerequisites: ME 143 or equivalent.

ME 245. Advanced Heat Transfer I. 3 Credits.
Analytical methods for multidimensional steady and transient heat conduction; phase change and moving boundaries. Thermal radiation exchange in enclosures; view factors; emitting/absorbing gases. Prerequisites: ME 144 or equivalent, or by Instructor permission.

ME 249. Computational Fluids Engr. 0 or 3 Credits.
Project-based. Computational methods for solving the Navier-Stokes equations and combined thermo-fluid flows; finite-differences and finite-volume techniques; use of standard commercial CFD software. Prerequisite: ME 143 or equivalent.

ME 250. Air Breathing Propulsion. 3 Credits.
Presents a study on air-breathing propulsion system. Initial focus will be on various types of engine systems, real and ideal parametric cycle analysis, and individual internal component performance. Will then move to contemporary propulsion topics and research that push aerospace systems to new flight envelopes. Prerequisites: ME 144, ME 240.

ME 252. Mechanical Behavior Materials. 3 Credits.
Isotropic and anisotropic elasticity; theory of plasticity; deformation mechanisms in crystalline solids; dislocation theory; creep behavior; advanced fatigue and fracture mechanisms. Prerequisites: ME 101; Instructor permission.

ME 255. Adv Engineering Materials. 3 Credits.
Advanced material processing; physical and mechanical principles of high-temperature alloys, light-weight materials, thin films, nanomaterials, and biomedical materials; elements of computational materials design. Prerequisites: ME 101; Instructor permission.

ME 257. Composite Materials. 3 Credits.

ME 259. Computational Solid Mechanics. 3 Credits.
Project-based. Computational methods using the finite element analysis (FEA) applied to linear elastic and non-linear problems in the mechanics of deformable solids and structures, contact mechanics, and fracture mechanics. Hands-on computational experience using a commercial FEA software. Prerequisites: ME 014, MATH 124, and MATH 271, or equivalent.

ME 265. QR: Integrated Product Dev. 3 Credits.
Project-based course focusing on the entire product life cycle. Team dynamics, process and product design, quality, materials, management, and environmentally-conscious manufacturing. Prerequisite: Senior standing. Cross-listed with: BSAD 293.

ME 270. Structural Dynamics. 3 Credits.
Vibrations, matrices, earthquake engineering, stability and wave propagation. Prerequisites: Senior/Graduate standing in Engineering or physical sciences, or Instructor permission. Cross-listed with: CE 272.

ME 271. Micro and Nano Systems. 3 Credits.
Operating principles, fabrication and design of engineered systems with submillimeter dimensions. Prerequisites: Senior/Graduate standing in Engineering or physical sciences.

ME 281. Seminar. 1 Credit.
Presentation and discussion of advanced mechanical engineering problems and current developments. Prerequisite: Senior/Graduate engineering enrollment.

ME 282. Seminar. 1 Credit.
Presentation and discussion of advanced mechanical engineering problems and current developments. Prerequisite: Senior/Graduate engineering enrollment.

ME 304. Adv Engineering Analysis I. 3 Credits.
Analytical methods for the solution of partial differential equations in engineering mechanics and physics, including: eigenfunction expansions; Fourier series; Sturm-Liouville theory and special functions. Prerequisites: Graduate standing in engineering, mathematics, or physical sciences or Instructor permission.

ME 305. Adv Engineering Analysis II. 3 Credits.
Advanced analytical techniques for problems in engineering mechanics and physics, including: integral transform methods Green’s functions, perturbation methods, and variational calculus. Prerequisites: ME 304 or equivalent.

ME 312. Bioengineering Systems. 3 Credits.
Advanced bioengineering design and analysis for current biomedical problems spanning molecular, cell, tissue, organ, and whole body systems including their interactions and emergent behaviors.

ME 336. Continuum Mechanics. 3 Credits.
Tensors, conservation laws, field equations for solids and fluids.

ME 338. Advanced Dynamics. 3 Credits.

ME 343. Advanced Fluid Dynamics. 3 Credits.
Stress in continuum; kinematics, dynamics; potential fields; Wing theory; Navier-Stokes equation; hydrodynamic stability; turbulence; laminar, turbulent boundary layer theory; transient flows; free laminar, turbulent flows; mixing.
ME 346. Advanced Gas Dynamics. 3 Credits.
Transonic flows; hypersonic flows and shock relations; boundary layer interactions; high-temperature gases and aero thermodynamics; rarefied flows; computational methods. Prerequisite: ME 240 or equivalent.

ME 350. Multiscale Modeling. 3 Credits.

ME 390. Internship. 1-18 Credits.
On-site supervised work experience combined with a structured academic learning plan directed by a faculty member or a faculty-staff team in which a faculty member is the instructor of record, for which academic credit is awarded. Offered at department discretion.

ME 391. Master’s Thesis Research. 1-18 Credits.
A course which is tailored to fit the interests of a specific student, which occurs outside the traditional classroom/laboratory setting under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

ME 394. Independent Graduate Research. 1-18 Credits.
Graduate student work on individual or small team research projects under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

ME 395. Advanced Special Topics. 1-18 Credits.
Advanced topics in recently developed technical areas. Prerequisites: three hours with Instructor permission.

ME 490. Internship. 1-18 Credits.
On-site supervised work experience combined with a structured academic learning plan directed by a faculty member or a faculty-staff team in which a faculty member is the instructor of record, for which academic credit is awarded. Offered at department discretion.

ME 491. Doctoral Dissertation Research. 1-18 Credits.
Graduate student work on individual or small team research projects under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

ME 494. Independent Graduate Research. 1-18 Credits.
Graduate student work on individual or small team research projects under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

ME 496. Advanced Special Topics. 1-18 Credits.
See Schedule of Courses for specific titles.

Physics Courses

PHYS 202. Experimental Physics II. 3 Credits.
Experiments in classical and modern physics. Prerequisites: PHYS 128; MATH 121; Junior standing.

PHYS 211. Classical Mechanics. 3 Credits.
Newtonian dynamics of particles and systems of particles, with applications to problems of special importance, such as driven and coupled harmonic oscillators and central field trajectories. Prerequisites: PHYS 152, MATH 121.

PHYS 213. Electricity & Magnetism. 3 Credits.
Fundamental principles of electricity and magnetism; electrostatic fields, and magnetic fields of steady currents. Electric and magnetic properties of matter and electromagnetic energy. Prerequisites: PHYS 152 or PHYS 125 and MATH 121. Credit not given for more than one of PHYS 213 or EE 141.

PHYS 214. Electromagnetism. 3 Credits.
Introduction to time dependent electromagnetic fields. Maxwell’s equations in vacuum and in matter. Electromagnetic waves and radiation. Prerequisite: PHYS 213. Credit not given for more than one of PHYS 214 or EE 241.

PHYS 222. Intro Biological Physics. 3 Credits.
General survey course in biological physics. Introduction to biological building blocks (proteins, lipids and nucleic acids) and macromolecular structure, thermostatistics of biological systems and two-state models, random walks and polymers, elasticity and mechanics of filaments and membranes, physics of water and molecular solvation, brownian motion and diffusion. Prerequisites: PHYS 012 or PHYS 152, MATH 121.

PHYS 242. Intro to Solid State Physics. 3 Credits.
Introduction to crystal structures, reciprocal lattices, lattice vibrations. Thermal properties of solids and free electron theory of metals and semiconductors. Elementary band theory and introduction to electronic transport theory. Prerequisite: PHYS 128.

PHYS 264. Nuclear & Elem Particle Physic. 3 Credits.
Introduction to theoretical and experimental aspects of nuclear and elementary particle physics. Prerequisite: PHYS 128; Junior standing.

PHYS 265. Thermal & Statistical Physics. 3 Credits.
Thermodynamics, kinetic theory, statistical mechanics. Prerequisites: PHYS 152 or PHYS 125 and MATH 121.

PHYS 273. Quantum Mechanics I. 3 Credits.
Introduction to nonrelativistic quantum mechanics. Schrodinger equation and applications to simple systems. Prerequisite: PHYS 128, PHYS 211.

PHYS 274. Applictns of Quantum Mechanics. 3 Credits.
Applications of Quantum Mechanics including Quantum Statistical Mechanics, Time-Independent and Time- Dependent Perturbation Theory, WKB Approximation, Variational Principle and Scattering. Prerequisite: PHYS 273.

PHYS 301. Mathematical Physics. 3 Credits.
Introduction to basic mathematical methods of theoretical physics; vector and tensor analysis, partial differential equations, orthogonal functions, complex variables and variational techniques. Prerequisites: PHYS 211, PHYS 214. Alternate years.

PHYS 305. Teaching of College Physics. 1 Credit.
Instructional strategies and techniques with application to the teaching of laboratories and recitations. Prerequisites: Undergraduate degree in Physics; Instructor permission.
PHYS 311. Advanced Dynamics. 3 Credits.
Classical mechanics presented as the basis of the concepts and methods of modern physics. Variational, Lagrangian, and Hamiltonian formulations, canonical transformations, continuous systems. Prerequisite: PHYS 211. Alternate years.

PHYS 313. Electromagnetic Theory. 3 Credits.
Development of Maxwell's theory of electromagnetism emphasizing its physical basis and the modes of mathematical description. Prerequisite: PHYS 214. Alternate years.

PHYS 322. Contemporary Physics. 0-6 Credits.
Topics of current interest in physics to be offered as student and faculty interest warrants. May be repeated for credit with department approval. Topics vary by offering; periodic offering at intervals that may exceed four years. Prerequisite: Instructor permission.

PHYS 333. Biological Physics. 3 Credits.
Physical principles of biological systems including advanced techniques in macromolecular structure (experimental and computational), molecular solvation and hydration models, thermostatistics, two-state models and cooperativity, elasticity and mechanics of soft tissues, chemical equilibria and reaction kinetics including enzymes. Prerequisites: PHYS 152, MATH 121, or Instructor permission.

PHYS 341. Solid State Physics. 3 Credits.
Introduction to crystal symmetry and the reciprocal lattice. Crystal binding and lattice vibrations. Thermal, electrical, and magnetic properties of solids, free electron theory of metals, and band theory. Prerequisites: PHYS 214, PHYS 265, PHYS 273 or their equivalents; Instructor permission.

PHYS 362. Quantum Mechanics II. 3 Credits.
Mathematical and physical foundations of nonrelativistic quantum mechanics from the unifying point of view of Dirac. Symmetry operations and the algebraic structure of quantum mechanics are emphasized. Prerequisite: PHYS 273. Alternate years.

PHYS 365. Statistical Mechanics. 3 Credits.
Following a review of thermodynamics, we study the fundamentals of classical and quantum statistical mechanics including ensembles, identical particles, Bose and Fermi statistics, phase-transitions and critical phenomena, renormalization group, irreversible processes and fluctuations. Prerequisites: PHYS 265 or equivalent.

PHYS 390. Internship. 1-18 Credits.
On-site supervised work experience combined with a structured academic learning plan directed by a faculty member or a faculty-staff team in which a faculty member is the instructor of record, for which academic credit is awarded. Offered at department discretion.

PHYS 391. Master's Thesis Research. 1-12 Credits.
PHYS 392. Independent Study. 1-18 Credits.
A course which is tailored to fit the interests of a specific student, which occurs outside the traditional classroom/laboratory setting under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

PHYS 394. Independent Graduate Research. 1-18 Credits.
Graduate student work on individual or small team research projects under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

PHYS 396. Special Topics. 1-18 Credits.
See Schedule of Courses for specific titles.

PHYS 397. Teaching Assistantship. 1-3 Credits.
Student service as a teaching assistant, usually in an introductory level course in the discipline, for which credit is awarded. Offered at department discretion.

PHYS 490. Internship. 1-18 Credits.
On-site supervised work experience combined with a structured academic learning plan directed by a faculty member or a faculty-staff team in which a faculty member is the instructor of record, for which academic credit is awarded. Offered at department discretion.

PHYS 491. Doctoral Dissertation Research. 1-18 Credits.
PHYS 492. Independent Study. 1-18 Credits.
A course which is tailored to fit the interests of a specific student, which occurs outside the traditional classroom/laboratory setting under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

PHYS 494. Independent Graduate Research. 1-18 Credits.
Graduate student work on individual or small team research projects under the supervision of a faculty member, for which credit is awarded. Offered at department discretion.

PHYS 496. Special Topics. 1-18 Credits.
See Schedule of Courses for specific titles.