MATERIALS SCIENCE

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 our 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 organometallics and small molecule semiconductors. 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 three tracks (engineering, physics and chemistry) 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
- Materials Science M.S.
- Materials Science Ph.D.

FACULTY

Clougherty, Dennis Paul; Professor, Department of Physics; PHD, Massachusetts Institute of Technology
Del Maestro, Adrian G; Assistant Professor, Department of Physics; PHD, Harvard University
Dubief, Yves C.; Associate Professor, School of Engineering; PHD, Institut National Polytechnique de Grenoble
Furis, Madalina Ioana; Associate Professor, Department of Physics; PHD, University of Buffalo
Headrick, Randall L.; Professor, Department of Physics; PHD, University of Pennsylvania
Hitt, Darren Lee; Professor, School of Engineering; PHD, Johns Hopkins University
Kotov, Valeri N.; Assistant Professor, Department of Physics; PHD, Clarkson University
Landry, Christopher C.; Professor, Department of Chemistry; PHD, Harvard University
Lee, Patrick Chang Dong; Assistant Professor, Department of Mechanical Engineering; PHD, University of Minnesota
Leenstra, Willem R.; Associate Professor, Department of Chemistry; PHD, University of Washington
Oldinski, Rachael; Assistant Professor, School of Engineering; PHD, Colorado State University
Sansoz, Frederic P.; Associate Professor, School of Engineering; PHD, Ecole Des Mines de Paris
Titcomb, Stephen; Associate Professor, School of Engineering; PHD, Lehigh University
Varhue, Walter John; Professor, School of Engineering; PHD, University of Virginia
Whalley, Adam; Assistant Professor, Department of Chemistry; PHD, Columbia University
White, Matthew S.; Assistant Professor, Department of Physics; PHD; University of Colorado
Waterman, Rory; Associate Professor, Department of Chemistry; PHD, University of Chicago
Wu, Jun-Ru; Professor, Department of Physics; PHD, University of California Los Angeles
Xia, Tian; Associate Professor, School of Engineering; PHD, University of Rhode Island
Yang, Jie; Associate Professor, Department of Physics; PHD, Princeton University

Chemistry Courses

CHEM 201. Advanced Chemistry Laboratory. 3 Credits.
Discussion and laboratory experiments using spectroscopy techniques (mass spectrometry, NMR, IR, UV/visible, and atomic spectroscopy) to solve problems in analytical, physical, and inorganic chemistry. Prerequisites: CHEM 121, and CHEM 142 or CHEM 144. CHEM 161 strongly recommended.

CHEM 202. Advanced Chemistry Laboratory. 2 Credits.
Laboratory problems requiring modern analytical, physical, and inorganic synthetic techniques. Journal article writing. Prerequisite: CHEM 201.

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 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. 2 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 142 or CHEM 144, and CHEM 162.

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 161 or CHEM 162 strongly recommended.

CHEM 223. Mass Spectrometry. 3 Credits.  
An in-depth treatment of modern mass spectrometry, instrumentation and techniques with discussion of biological and chemical applications. Prerequisites: CHEM 142 or CHEM 144, and CHEM 221, or Instructor permission.

CHEM 225. Electroanalytical Chemistry. 3 Credits.  
Principles and techniques of modern electroanalytical chemistry and applications to redox chemistry. Heterogeneous effects; voltammetry; electron-transfer processes and reactions. Prerequisite: CHEM 221.

CHEM 226. Analytical Spectroscopy. 3 Credits.  
Principles of optical spectroscopic methods of analysis. Emphasis on theory and practice of atomic spectroscopy and new molecular spectroscopic methods. Prerequisite: CHEM 221 Alternate years.

CHEM 227. Spec Topics in Analytical Chem. 1-3 Credits.  
Selected topics of current interest in analytical chemistry. New techniques and methodologies, especially in chemical instrumentation. Credit as arranged.

CHEM 228. Spec Topics in Analytical Chem. 1-4 Credits.  
Selected topics of current interest in analytical chemistry. New techniques and methodologies, especially in chemical instrumentation. Credit as arranged.

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 142 or CHEM 144.

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. Topics include ligand field theory, magnetism, magnetic resonance, Mossbauer spectroscopy, and X-ray crystallography. Prerequisites: CHEM 131 or CHEM 231, and CHEM 161.

CHEM 237. Special Topics: Inorganic. 1-3 Credits.  
Areas of current interest involving inorganic systems.

CHEM 238. Special Topics: Inorganic. 1-3 Credits.  
Areas of current interest involving inorganic systems.

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 251. Physical Organic Chemistry. 3 Credits.  
Experimental and computational techniques for determining and interpreting structure, properties and reactivity of organic molecules, with an emphasis on the mechanisms of organic reactions. Prerequisites: CHEM 142 or CHEM 144, and CHEM 161, or graduate standing.

CHEM 257. Special Topics in Organic Chem. 1-3 Credits.  
Advanced level discussion of specific topics in organic chemistry of current interest such as photochemistry, carbenes, bioorganic chemistry, magnetic resonance, etc. Credit as arranged.

CHEM 258. Special Topics in Organic Chem. 1-3 Credits.  
Advanced level discussion of specific topics in organic chemistry of current interest such as photochemistry, carbenes, bioorganic chemistry, magnetic resonance, etc. Credit as arranged.

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 262. Chemical Thermodynamics. 3 Credits.  
Classical and statistical thermodynamics. Systematic study of applications of thermodynamics to chemical problems. Prerequisites: CHEM 161 and CHEM 162.

CHEM 264. Adv Quantum & Spectroscopy. 3 Credits.  
In-depth theoretical discussion of molecular states, their symmetry, and transition probabilities. Explicit treatment of vibrations, electronic states, and vibronic spectroscopy. Prerequisites: CHEM 161 and MATH 121.

CHEM 267. Special Topics: Physical. 1-3 Credits.  
Selected topics of current interest in physical chemistry.

CHEM 268. Special Topics: Physical. 1-3 Credits.  
Selected topics of current interest in physical chemistry.

CHEM 285. Special Topics. 1-3 Credits.  
CHEM 286. Special Topics. 1-3 Credits.  
CHEM 318. Current Topics in Chemistry. 0 or 1 Credits.  
Survey of current topics in the chemistry literature.
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 391. Master's Thesis Research. 1-18 Credits.

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

CHEM 488. Rsch Prob Conception&Solution. 1 Credit.
Independent origination of research problems and the methods of their solution.

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

Electrical Engineering Courses

EE 209. Transmission Line Analysis. 3 Credits.
Fourier-Laplace transform analysis of steady-state and transient phenomena on transmission lines. Phasor representation and complex variable analysis. Prerequisite: MATH 271.

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. Prerequisite: EE 171 or ME 111. Cross-listed with: ME 210.

EE 212. Computer Vision. 3 Credits.
Introduction to computer vision systems for interactive and industrial applications using both hard/software computational approaches. Pre/co-requisites: CS 110; MATH 122 (preferred) or MATH 124 or MATH 271.

EE 213. Systems & Synthetic Biology. 3 Credits.
Applying engineering tools to the design and analysis of biomolecular processes; gene regulatory networks; nonlinear dynamics in molecular biology; biological circuit design; biological signal processing. Prerequisites: Background required: Differential Equations, Linear Algebra, Programming. Cross-listed with: CSYS 213, ME 213.

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. Digital Computer Design I. 3 Credits.

EE 219. Principles VLSI System Design. 3 Credits.

EE 221. Biomed Measmnts Instrum & Sys. 3 Credits.
Biomedical and clinical engineering in research, industry, and health care institutions. Measurement techniques and instrumentation. Integrated biomedical monitoring, diagnostic, and therapeutic systems. Co-requisites: EE 121, ANPS 020; Instructor permission. Alternate years.

EE 222. Biomed Measmnts Instrum & Sys. 3 Credits.
Biomedical and clinical engineering in research, industry, and health care institutions. Measurement techniques and instrumentation. Integrated biomedical monitoring, diagnostic, and therapeutic systems. Co-requisites: EE 121, ANPS 020; Instructor permission. Alternate years.

EE 227. Biomed Measmnts Instrum & Sys. 3 Credits.
Biomedical and clinical engineering in research, industry, and health care institutions. Measurement techniques and instrumentation. Integrated biomedical monitoring, diagnostic, and therapeutic systems. Co-requisites: EE 121, ANPS 020; Instructor permission. Alternate years.

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. Prerequisite: Senior standing in Engineering or Physics.

EE 231. Digital Computer Design II. 3 Credits.
Memory designs, error control, high-speed addition, multiplication, and division, floating-point arithmetic, cpu enhancements, testing and design for testability. Prerequisite: EE 231.

EE 232. Digital Computer Design II. 3 Credits.
Memory designs, error control, high-speed addition, multiplication, and division, floating-point arithmetic, cpu enhancements, testing and design for testability. Prerequisite: EE 231.

EE 233. Microprocessor Systems & Appl. 0 or 4 Credits.
Basic principles of mini/microcomputers; A/D; D/A; channels, magnetic devices, display devices, mechanical devices; interface designs of analog systems to mini/microcomputers; principles of microprogramming; bit-slice-based microcomputers. Prerequisite: Department permission; CS 101 desirable.
EE 241. Electromagnetic Wave Theory. 3 Credits.
Electromagnetic radiation and wave propagation in complex media and systems: angular spectrum of plane waves, dispersive pulse propagation, applications to communications, imaging and remote sensing. Prerequisite: EE 141 or equivalent.

EE 245. Quantum Electronics. 3 Credits.
A theoretical description of light-matter interactions in photon emitting resonant cavities. A practical understanding of laser design and operation. Prerequisite: EE 141.

EE 247. Physical Optics. 3 Credits.

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 163.

EE 262. Solid-State Materials&Devices. 3 Credits.

EE 266. Science & Tech Integrated Cir. 3 Credits.
Science and technology of integrated circuit fabrication. Interaction of processing with material properties, electrical performance, economy, and manufacturability. Prerequisite: EE 163 or EE 261; Co-requisite: EE 164 or EE 262.

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: STAT 143, STAT 151, or STAT 153.

EE 273. Digital Communications. 3 Credits.
Digital modulation/demodulation methods and BER performance; source entropy and channel capacity; optimal detection; convolutional codes and decoding algorithms. Pre/co-requisites: EE 174 and STAT 151.

EE 275. Digital Signal Processing. 3 Credits.
Sampling and reconstruction of signals. DFT, FFT and the z-transform. FIR and IIR filter design. Speech coding. Accompanying lab: EE 289. Pre/co-requisites: EE 171; Instructor permission.

EE 276. Image Processing & Coding. 3 Credits.
Image enhancement techniques by point and spatial operations. Data compression techniques to include scalar quantization, entropy coding, transform and sub-band coding. Labs on PC hardware; PC and Unix-based software. Prerequisite: EE 275.

EE 277. Image Anyl&Pattern Recognition. 3 Credits.

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 174 or Instructor permission.

EE 281. Materials Science Seminar. 1 Credit.
Presentation and discussion of advanced electrical engineering problems and current developments. Prerequisite: Senior or Graduate Engineering enrollment.

EE 295. Special Topics. 1-18 Credits.
Special topics in developing areas of Electrical Engineering. Prerequisite: Senior standing, or Instructor permission.

EE 297. Critical Thinking. 3 Credits.
Economic, social, and technological issues. Use of rhetorical methods and skills. Theories of argument, reasoning, and methodology. Prerequisites: MATH 230, MATH 271, MATH 143, or MATH 243.

EE 299. Senior Project. 1-3 Credits.
Graduate Engineering enrollment.

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 310. Digital Control Systems. 3 Credits.
Digital control system analysis and design using transform, algebraic, and state space methods. Sampled data systems, stability, quantization effects, sample rate selection, computer-based realization. Prerequisite: EE 210 or Instructor permission.

EE 312. Intro Optimum Control Systems. 3 Credits.
Optimal control problem formulation and solution; including the calculus of variations, Pontryagin’s maximum principle, Hamilton-Jacobi theory, dynamic programming, and computational methods. Prerequisite: EE 210.

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: EE 201 or MATH 230.
EE 338. Semiconductor Dev Model & Simul. 3 Credits.
Analysis and application of computer models for semiconductor process and device simulation. Strategies for development of device models for circuit simulation. Prerequisites: EE 262; Instructor permission.

EE 341. ST: Electromagnetic Field Thry. 3 Credits.
For advanced students in the field of electromagnetism. Topics selected from special interests of staff with lectures and readings from current literature.

EE 352. Adv Semicond Device Phys & Des. 3 Credits.
MOSFET, bipolar, and CMOS device parameters, their characterization, and their relation to process technology. Description and use of computer-aided process and device models. Prerequisite: EE 262.

EE 354. MOS Analog Intergrtd Circ Dsgn. 3 Credits.
Analysis and design of MOS analog integrated circuits. Each student will design, layout, test, and document an analog integrated circuit using computer-aided-design techniques. Prerequisites: EE 338.

EE 355. Optoelectronic Devices. 3 Credits.
Optical and electro optical properties of semiconductors. Applications to photodetectors, solar cells, light emitting diodes and lasers. Prerequisites: EE 142, EE 261.

EE 356. Solid State & Semicond Thry. 3 Credits.

EE 371. Estimation Theory. 3 Credits.
Foundations of linear and nonlinear least squares estimation, smoothing and prediction, computational aspects, Kalman filtering, nonlinear filtering, parameter identification, and adaptive filtering. Applications to students' research. Pre/co-requisite: STAT 151.

EE 373. Adv Topics in Communications. 3 Credits.
Advanced topics of current interest in communication systems. Topics may include channel coding/decoding, software radio, ad-hoc networks, wireless systems, etc. Prerequisite: EE 273 or Instructor permission.

EE 391. Master's Thesis Research. 1-18 Credits.
EE 392. Master's Project. 1-3 Credits.
Master's Project.

EE 395. Advanced Special Topics. 1-18 Credits.
Advanced topics of current interest in electrical engineering. Prerequisite: Instructor permission.

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

Mathematics Courses

MATH 207. Probability Theory. 3 Credits.
Distributions of random variables and functions of random variables. Expectations, stochastic independence, sampling and limiting distributions (central limit theorems). Concepts of random number generation. Prerequisites: MATH 121; STAT 151 or STAT 153 recommended. Cross-listed with: STAT 251, BIOS 251.

MATH 221. Deterministic Models Oper Rsch. 3 Credits.
The linear programming problem. Simplex algorithm, dual problem, sensitivity analysis, goal programming. Dynamic programming and network problems. Prerequisites: MATH 122 or MATH 124; MATH 121 desirable. Cross-listed with: CSYS 221.

MATH 222. Stochastic Models in Oper Rsch. 3 Credits.
Development and solution of some typical stochastic models. Markov chains, queueing problems, inventory models, and dynamic programming under uncertainty. Prerequisite: MATH 207, STAT 151.

MATH 230. 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. Mathematical Models & Analysis. 3 Credits.
Techniques of Undergraduate 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 236. Calculus of Variations. 3 Credits.

MATH 237. 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, MATH 124 or MATH 271; knowledge of computer programming.

MATH 238. Applied Computational Methods. 3 Credits.
Direct and iterative methods for solving linear systems; numerical solution of ordinary and partial differential equations. Focus will be on application of numerical methods. Prerequisites: MATH 121; MATH 122 or MATH 124 or MATH 271.

MATH 240. Fourier Series & Integral Trans. 3 Credits.
Fourier series, orthogonal functions, integral transforms and boundary value problems. Prerequisite: MATH 230 or MATH 271.

MATH 241. Anyl in Several Real Vars I. 3 Credits.
Properties of the real numbers, basic topology of metric spaces, infinite sequences and series, continuity. Prerequisites: MATH 052; MATH 121; MATH 122 or MATH 124.
MATH 242. Any Several Real Variables 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 251. Abstract Algebra I. 3 Credits.
Basic theory of groups, rings, fields, homomorphisms, and isomorphisms. Prerequisite: MATH 052; MATH 122 or MATH 124.

MATH 252. 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 255. Elementary Number Theory. 3 Credits.
Divisibility, prime numbers, Diophantine equations, congruence of numbers, and methods of solving congruences. Prerequisite: MATH 052 or MATH 054.

MATH 257. Topics in Group Theory. 3 Credits.
Topics may include abstract group theory, representation theory, classical groups, Lie groups. Prerequisite: MATH 251.

MATH 260. Foundations of Geometry. 3 Credits.
Geometry as an axiomatic science; various non-Euclidean geometries; relationships existing between Euclidean plane geometry and other geometries; invariant properties. Prerequisite: MATH 022 and either MATH 052 or MATH 054.

MATH 264. Vector Analysis. 3 Credits.
Gradient, curl and divergence, Green, Gauss, and Stokes Theorems, applications to physics, tensor analysis. Prerequisite: MATH 122; MATH 122 or MATH 124 or MATH 271.

MATH 266. 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. Co-requisite: MATH 271 or MATH 230. Cross-listed with: CSYS 266.

MATH 268. Mathematical Biology & Ecology. 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 Instructor permission. Cross-listed with: CSYS 268.

MATH 271. Adv Engineering Mathematics. 3 Credits.
Differential equations and linear algebra, including linear ordinary differential equations, Laplace transforms, matrix theory, and systems of differential equations. Examples from engineering and physical sciences. Prerequisite: MATH 121. Credit not granted for both MATH 230 and MATH 271. No credit for Mathematics majors.

MATH 272. Applied Analysis. 3 Credits.
Basics of Fourier series, partial differential equations of mathematical physics, functions of a complex variable, Cauchy's theorem, integral formula. Prerequisites: MATH 230 or MATH 271.

MATH 273. 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 or MATH 054.

MATH 274. Numerical Linear Algebra. 3 Credits.
Direct and iterative methods for solving linear equations, least square factorization methods, eigenvalue computations, ill-conditioning and stability. Prerequisite: MATH 237.

MATH 295. Special Topics. 1-18 Credits.
For advanced students in the indicated fields. Lectures, reports, and directed readings on advanced topics. Credit as arranged. Offered as occasion warrants.

MATH 300. Principles of Complex Systems. 3 Credits.
Introduction to fundamental concepts of complex systems. Topics include: emergence, scaling phenomena, and mechanisms, multiscale 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. 4 Credits.
Differentiation, integration, Cauchy-Riemann equations, infinite series, properties of analytic continuation, Laurent series, calculus of residues, contour integration, meromorphic functions, conformal mappings, Riemann surfaces. Prerequisite: MATH 242.

MATH 332. Approximation Theory. 3 Credits.
Interpolation and approximation by interpolation, uniform approximation in normed linear spaces, spline functions, orthogonal polynomials. Least square, and Chebychew approximations, rational functions. Prerequisites: MATH 122 or MATH 124; MATH 237.

MATH 333. Thry Functions Real Variables. 4 Credits.
The theory of Lebesgue integration, Lebesgue measure, sequences of functions, absolute continuity, properties of LP-spaces. Prerequisite: MATH 242.
MATH 335. Advanced Real Analysis. 3 Credits.
L2-spaces, LP-spaces; Hilbert, Banach spaces; linear functionals, linear operators; completely continuous operators (including symmetric); Fredholm alternative; Hilbert-Schmidt theory; unitary operators; Bochner’s Theorem; Fourier-Plancherel, Watson transforms. Prerequisites: MATH 333.

MATH 336. Advanced Real Analysis. 3 Credits.
L2-spaces, LP-spaces; Hilbert, Banach spaces; linear functionals, linear operators; completely continuous operators (including symmetric); Fredholm alternative; Hilbert-Schmidt theory; unitary operators; Bochner’s Theorem; Fourier-Plancherel, Watson transforms. Prerequisite: MATH 333 and MATH 335.

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 242.

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. Prerequisite: MATH 252.

MATH 353. Point-Set Topology. 3 Credits.
Topological spaces, closed and open sets, closure operators, separation axioms, continuity, connectedness, compactness, metrization, uniform spaces. Prerequisite: MATH 241.

MATH 354. Algebraic Topology. 3 Credits.
Homotopy, Seifert-van Kampen Theorem; simplicial, singular, and Čech homology. Prerequisite: MATH 241 or MATH 353.

MATH 373. Topics in Combinatorics. 3 Credits.
Topics will vary each semester and may include combinatorial designs, coding theory, topological graph theory, cryptography. Prerequisite: MATH 251 or MATH 273.

MATH 382. Seminar. 1 Credit.
Topical discussions with assigned reading. Required of M.S. degree candidates.

MATH 391. Master’s Thesis Research. 1-18 Credits.
Subject will vary from year to year. May be repeated for credit.

MATH 395. Special Topics. 1-18 Credits.

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

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.

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 207. Bioengineering. 3 Credits.
Introduction to bioengineering including biomechanics, rehabilitation, instrumentation, imaging, biomaterials, and transport. Pre/co-requisites: Senior/Graduate standing in Engineering; Instructor permission.

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. Pre/co-requisites: Senior/Graduate standing in Engineering; Instructor permission.

ME 209. Biomechanics: Transport Proc. 3 Credits.
Transport and kinetic processes to vascular biology, respiratory mechanics and medicine. Steady and unsteady laminar flow, pulse wave reflections, curved and collapsible tube flow, turbulence. Pre/co-requisites: Senior/Graduate standing in Engineering; Instructor permission.

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. Prerequisites: EE 171 or ME 111. Cross-listed with: EE 210.

ME 213. Systems & Synthetic Biology. 3 Credits.
Applying engineering tools to the design and analysis of biomolecular processes; gene regulatory networks; nonlinear dynamics in molecular biology; biological circuit design; biological signal processing. Prerequisite: Background required: Differential Equations, Linear Algebra, Programming. Cross-listed with: CSYS 213, EE 213.

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 230. Orbital Mechanics. 3 Credits.
Motion of spacecraft in a central gravitational field. Two and restricted three-body problems; Kepler’s equation; orbital maneuvers and rendezvous; interplanetary and lunar trajectories. Prerequisite: ME 012. Co-requisites: ME 111 or Instructor permission.

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 235. Turbomach Vibration Anyl/Tstng. 2 Credits.
Vibration in rotating machines; vibration measurement techniques; machinery condition and degradation; condition monitoring and predictive maintenance; industrial vibration techniques including proximity probes, accelerometers, FFT analyzer. Prerequisite: ME 244.

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 241. Combustion Processes. 3 Credits.
Combustion thermodynamics; chemical kinetics; laminar flames, premixed and diffusion; turbulent flames; ignition, explosion, and detonation; droplet combustion; flame spread; large scale fires; rocket combustion. Prerequisite: Senior/Graduate standing.

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 244. Intro to Turbomachinery Anyl. 2 Credits.
Fundamental turbomachinery principles of fluid mechanics, thermodynamics, and structural analysis; basic equations and computational techniques for analysis and design to model and evaluate turbomachinery. Prerequisite: ME 243, MATH 271.

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 246. Centrifugal Compressors. 2 Credits.
Fluid dynamic and thermodynamic principles of centrifugal compressor design and design practice; limits of stable operation and instability prediction and control. Prerequisite: ME 244.

ME 247. Centrifugal Pumps. 2 Credits.
Centrifugal pump design principles and practice; performance limits; cavitation; design tools and pump design optimization. Prerequisite: ME 244.

ME 248. Turbomachinery Special Topics. 1 or 2 Credits.
Content in axial fans/compressors; axial, radial, or steam turbines; CFD, dynamics/rotordynamics, or materials for turbo-machinery; power plant or refrigeration cycle developments; turbocharged and compound IC-engines. Prerequisite: ME 244.

ME 249. Computational Fluids Engr. 0 or 3 Credits.
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 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 253. Corrosion of Materials. 3 Credits.

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: Senior/Graduate standing; or Instructor permission.

ME 257. Composite Materials. 3 Credits.
ME 259. Computational Solid Mechanics. 3 Credits.
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. Integrated Product Developmnt. 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. Cross-listed with: BSAD 293.

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 283. Lab Techniques Turbomach Dev. 2 Credits.
Instruments and transducers for performance, flow, and structural measurements in turbo-machinery; the role of test data in design and development; experimental data acquisition and processing. Prerequisite: ME 244.

ME 285. Biomedical Engineering Seminar. 1 Credit.
Presentation and discussion of advanced biomedical engineering problems and current research developments. Prerequisite: Senior/Graduate engineering enrollment.

ME 295. Advanced Special Topics. 1-18 Credits.
Content is dictated by expanding professional interest in newly developing, or recently developed, technical areas in which there is particular need or opportunity. 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. Cross-listed with: CE 304.

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. Cross-listed with: CE 305.

ME 312. Adv 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. Cross-listed with: CSYS 312.

ME 320. Special Problems in Elasticity. 3 Credits.
Advanced topics in the theory of elasticity in which there is a particular student and staff interest.

ME 321. Special Problems in Fluid Mech. 3 Credits.
Advanced topics in fluid mechanics in which there is a particular student and staff interest.

ME 322. Special Problems in Dynamics. 3 Credits.
Advanced topics in dynamics in which there is a particular student and staff interest.

ME 323. Special Prob in Thermodynamics. 3 Credits.
Advanced topics in thermodynamics in which there is a particular student and staff interest.

ME 324. Spec Problems in Heat Transfer. 3 Credits.
Advanced topics in heat transfer in which there is a particular student and staff interest.

ME 325. Special Problems in Materials. 3 Credits.
Advanced topics in behavior of materials in which there is a particular student and staff interest.

ME 330. Matrix Meth in Struct Dynamics. 3 Credits.
Matrices, eigenvalue problems, forced vibration, wave propagation.

ME 332. Engineering Elasticity. 3 Credits.
Tensors, complex variables, variational methods.

ME 333. Stress Analysis. 3 Credits.
Theory and experimental method of measuring static and dynamic stress and strain.

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

ME 338. Advanced Dynamics. 3 Credits.

ME 342. Advanced Combustion. 3 Credits.
equations of reacting mixtures; modeling of steady and unsteady combustion, homogeneous/heterogeneous systems; ignition, explosions, detonations; combustion aerodynamics: turbulence, swirl, and sprays. Prerequisite: ME 241 or equivalent.
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 344. Adv Eng Thermodynamics II. 3 Credits.
Microscopic thermodynamics; Maxwell-Boltzmann, Bose-Einstein, Fermi-Dirac statistics; kinetic theory of gases; transport properties, compressed gases, liquids, solid states; chemical systems; irreversible processes; fluctuations.

ME 345. Advanced Heat Transfer II. 3 Credits.
Advanced treatment of forced and free convection; thermal boundary layers; analytical and approximate solution methods. Phase change heat transfer. Micro/nano-scale heat transfer. Prerequisite: ME 245 or equivalent.

ME 346. Advanced Gas Dynamics. 3 Credits.
Transonic flows; hypersonic flows and shock relations; boundary layer interactions; high-temperature gases and aerothermodynamics; rarefied flows; computational methods. Prerequisite: ME 240 or equivalent.

ME 350. Multiscale Modeling. 3 Credits.

ME 371. Adv Engr Des Anyl&Synthesis I. 4 Credits.
Application of fundamental concepts, principles of advanced mathematics, physics, mechanics, electricity, thermodynamics, fluid dynamics, heat transfer, and decision-making processes to design, analysis, synthesis of complex engineering systems.

ME 372. Systems Engineering. 3 Credits.
Advanced course in systems engineering, reliability, maintainability, safety, and human factors engineering. Case studies. Prerequisites: ME 371 or Instructor permission.

ME 373. Integ Mechanism Design Anyl. 3 Credits.
Application of system analysis, rigid body dynamics, finite elements, fatigue analysis and structural dynamics to an integrated approach to mechanisms design. Prerequisites: ME 371 or Instructor permission.

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

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

ME 491. Doctoral Dissertation Research. 0-18 Credits.

Physics Courses

PHYS 201. Experimental Physics I. 3 Credits.
Experiments in classical and modern physics. Prerequisites: PHYS 128; MATH 121; Junior standing.

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. Biological Physics. 3 Credits.
Physical laws, processes, and interactions pertaining to biological systems. 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 257. Modern Astrophysics. 3 Credits.
Stellar structure and evolution, compact objects, the interstellar medium, galactic structure, gravitational theory, and cosmology, the formation of our solar system and terrestrial life. Prerequisite: One 100-level course in physical science or engineering. Cross-listed with: ASTR 257.

PHYS 258. Relativity. 3 Credits.
Development of Einstein's theory of special relativity. Lorentz transformation, time dilation, length contraction, mass variation, relative velocities. Introduction to four-dimensional space. Concepts of general relativity. Applications selected from astrophysics, elementary particles, etc. 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. Applications 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 295. Advanced Special Topics. 1-18 Credits.
See Schedule of Courses for specific titles.

PHYS 296. Advanced Special Topics. 1-18 Credits.
See Schedule of Courses for specific titles.

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 321. Theoretical Physics. 1-6 Credits.
For research students interested in pursuing topics of general and departmental research interest in theoretical physics. Prerequisite: Instructor permission. Offered as occasion warrants.

PHYS 323. 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. Prerequisite: Instructor permission.

PHYS 331. Biological Physics. 1-3 Credits.
For research students in the field of biological physics. Lectures, reports, and directed readings related to the research of the Department and the field generally. May be repeated for credit with departmental approval. Prerequisite: Instructor permission. Offered as occasion warrants.

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 351. Seminar: Physics of Materials. 1-3 Credits.
For research students in the field of the physics of materials. Lectures, reports, and directed readings related to the research for the department and the field generally. May be repeated for credit with departmental approval. Prerequisite: Instructor permission. Offered as occasion warrants.

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 391. Master’s Thesis Research. 1-12 Credits.