MATERIALS SCIENCE AND ENGINEERING (EG) {MSE}

099. Undergraduate Research and/or Independent Study. (C) Open to all students

An opportunity for the student to become closely associated with a professor (1) in a research effort to develop research skills and technique and/or (2) to develop a program of independent in-depth study in a subject area in which the professor and student have a common interest. The challenge of the task undertaken must be consistent with the student's academic level. To register for this course, the student and professor jointly submit a detailed proposal to the undergraduate curriculum chairman no later than the end of the first week of the term. Note: a maximum of 2 c.u. of MSE 099 may be applied toward the B.A.S. or B.S.E. degree requirements.

215. Introduction to Nanoscale Functional Materials. (B) Prerequisite(s): MSE 221.

The purpose of this first course in the major is to introduce the student to key concepts underlying the design, properties and processing of nanoscale functional materials, and how they are employed in practical applications. Fundamental chemical and physical principles underlying the properties of electronic, dielectric and magnetic materials will be developed in the context of metals, semiconductors, insulators, crystals, glasses, polymers and ceramics. Miniaturization and the nanotechnology revolution confronts materials science with limitations and opportunities; examples in which nanoscale materials are really different from our macro world experience will be explored.

L/R 220. Structural Materials. (A) Prerequisite(s): Knowledge of basic calculus and chemistry.

This course provides an introduction to the fundamental concepts of Materials Science through an examination of the structure, property, performance relationship for synthetic and biologic structural materials with a focus on surgical implants and medical devices. Consideration is given to issues of biocompatibility, degradation of materials by the biologic systems, and biologic response to artificial materials. Particular attention will be given to the materials of total hip and knee prostheses and their relationship to the long term outcomes in hip and knee arthroplasty.

221. Quantum Physics of Materials. (C) Prerequisite(s): PHYS 140, 141 concurrent and MATH 240. Meets Natural Science Requirement

The course is directed at the development of a background in basic physics required to understand the behavior of electrons in atoms, molecules and solids. Examples to illustrate the application of these techniques will be centered in the free and nearly free electron theory of solids. The application of modern physics to many state-of-the-art materials analysis techniques will be demonstrated throughout the course.

250. Nano-scale Materials Lab. (B) Prerequisite(s): MSE 220.

The course provides an in-depth experimental introduction to key concepts in materials and the relationships between nanoscale structure, the properties and performance. The use of laboratory methods to examine the structure of materials, to measure the important properties, and to investigate the relationship between structure and properties is covered. Emphasis is placed on a complete exposure of Nano and Materials science as a field. Most experiments require multiple laboratory sessions, with priority given to experiments in which students explore the entire range of materials science, from the synthesis of materials and the characterization of structure, thermodynamics and composition, to the measurement of properties and discussion of applications. Students are able to realize working devices as an end product of the key laboratories in this course. Practice in oral and written communication is realized through course assignments.

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260. Energetics of Macro and Nano-scale Materials. (B) Prerequisite(s): CHEM 101 or 102.

Basic principles of chemical thermodynamics as applied to macro and nano-sized materials. This course will cover the fundamentals of classical thermodynamics as applied to the calculation and prediction of phase stability, chemical reactivity and synthesis of materials systems. The size-dependent properties of nano-sized systems will be explored through the incorporation of the thermodynamic properties of surfaces. The prediction of the phase stability of two and three component systems will be illustrated through the calculation and interpretation of phase diagrams for metallic, semiconductor, inorganic, polymeric and surfactant systems.

330. (BE 330) Soft Materials. (A) Prerequisite(s): Junior or Senior standing, CHEM 102.

This course will serve as an introduction of soft condensed matter to students with background in chemistry, physics and engineering. It covers general aspects of fundamental interactions between soft materials with applications involving polymers, colloids, liquid crystals, amphiphiles, food and biomaterials.

360. Structure at the Nanoscale. (A)

Basic principles of material structure and organization from nano to macro sizes. This course will cover the fundamentals of materials structure including the crystalline, liquid crystalline and glassy states as well as 1-D, 2-D and 3-D structure and defects. Examples will be used from the different classes of materials - metallic, semiconductor, inorganic, polymeric - with particular emphasis on important components of structure on the nanoscale including particles, surfaces, interfaces and defects.

393. Materials Selection. (B) Prerequisite(s): MSE 220, Junior or Senior Standing.

Throughout mankind's history, materials have played a critical role in civilization and technology. The selection of materials has been based on availability and functionality. The rapid advances of materials technologies in the last 150 years, however, have made nearly all classes and forms of materials available, at a cost. Therefore, in theory at least, materials selection can now proceed on a rational basis as an optimization process. In this course, we will focus on structural applications where mechanical design is central. By the end of the course, the students can expect to acquire a level of engineering familiarity with a broad range of materials, and be prepared to undertake material design projects in the future.

405. (MEAM405, MEAM505, MSE 505) Mechanical Behavior of Macro/Nanoscale Materials. (A)

The application of continuum and microstructural concepts to consideration of the mechanics and mechanisms of flow and fracture in metals, polymers and ceramics. The course includes a review of tensors and elasticity with special emphasis on the effects of symmetry on tensor properties. Then deformation, fracture and degradation (fatique and wear) are treated, including mapping strategies for understanding the ranges of material properties.

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430. (CBE 430, CBE 510, MSE 580) Polymers and Biomaterials. (A) Prerequisite(s): MSE 260 or equivalent course in thermodynamics or physical chemistry (such as BE 223, CHE 231, CHEM 221, MEAM 203).

Polymer is one of the most widely used materials in our daily life, from the rubber tires to clothes, from photoresists in chip manufacturing to flexible electronics and smart sensors, from Scotch tapes to artificial tissues. This course teaches entry-level knowledge in polymer synthesis, characterization, thermodynamics, and structure-property relationship. Emphasis will be on understanding both chemical and physical aspects and polymer chain size/dimension that drive the molecular, microscopic and macroscopic structures and the resulting properties. We will discuss how to apply polymer designs to advance nanotechnology, electronics, energy and biotechnology. Case studies include thermodynamics of block copolymer thin films and their applications in nanolithography, shape memory polymers, hydrogels, and elastomeric deformation and applications.

440. Phase Transformations. (B)

The state of matter is dependent upon temperature, thermal history, and other variables. In this course the science of structural transitions is treated, with the purpose in mind of utilizing them for producing materials with superior properties. The subjects covered include the methods of structural analysis, solidification, solid state transformation, and order-disorder transition.

460. Computational Materials Science. (C) Prerequisite(s): Junior or Senior Standing. Ability to write simple computer codes would be an advantage.

This course provides an introduction to modeling and simulation in materials science, covering continuum methods (e.g. finite element methods) and atomistic and molecular simulation (e.g. molecular dynamics). These tools play an increasingly important role in modern engineering. You will get hands-on training in both the fundamentals and applications of these methods to key engineering problems. The lectures will provide an exposure to areas of application, based on the scientific exploitation of the power of computation. We will use software packages (Comsol and LAMMPS) and thus extensive programming skills are not required. Matlab background needed for the course will be covered in a self-contained module.

500. Experimental Methods in Materials Science. (A) Prerequisite(s): Permission of the Undergraduate Curriculum Chair and Instructor.

This laboratory course introduces students to a variety of experimental methods used in materials science and engineering. Hands-on training will be provided for atomic force microscopy, X-ray diffraction and scattering, mechanical testing with image capture, Rutherford backscattering, and dynamic light scattering. Students will use numerous software packages for data collection and analysis, as well as being introduced to LabVIEW as a method for customizing experiments. In addition, students will see demonstrations of scanning electron microscopy, transmission electron microscopy, and electron diffraction and analyze data from these methods

465. (MSE 565) Fabrication and Characterization of Micro and Nanostructured Devices. (C)

This course surveys various processes that are used to produce materials structured at the micron and nanometer scales for electronic, optical and chemical applications. Basic principles of chemistry, physics, thermodynamics and surface/interfacial science are applied to solid state, liquid, and colloidal approaches to making materials. The approaches to nano- and microfabrication: photolithography, soft lithography, nanoimprint lithography, 3D printing and self-assembly, are covered. The course is heavily lab based, with 25% of class time and 30% of the homework devoted to hands on experiences. Lab assignments are a series of structured individual/group projects. Evaluation is based on 3-4 lab reports, 4 problem sets with journal paper reading assignment, and a final project design.

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495. Senior Design. (A)

Independent student or team research on the design and construction of an original experimental or theoretical project related to materials science. The results of this project are presented at the end of the year in the form of a thesis and in an oral presentation to peers and faculty.

496. Senior Design. (B)

Independent student or team research on the design and construction of an original experimental or theoretical project related to materials science. The results of this project are presented at the end of the year in the form of a thesis and in an oral presentation to peers and faculty.

505. (MEAM405, MSE 405) Mechanical Properties of Macro/Nanoscale Materials. (A)

The application of continuum and microstructural concepts to consideration of the mechanics and mechanisms of flow and fracture in metals, polymers and ceramics. The course includes a review of tensors and elasticity with special emphasis on the effects of symmetry on tensor properties. Then deformation, fracture and degradation (fatique and wear) are treated, including mapping strategies for understanding the ranges of material properties.

507. (MEAM507) Fundamentals of Materials. (C)

This course will provide a graduate level introduction to the science and engineering of materials. It is designed specifically to meet the needs of students who will be doing research that involves materials but who do not have an extensive background in the field. The focus is on fundamental aspects of materials science and will emphasize phenomena and how to describe them . The course assumes an undergraduate background in any area of physical/chemical science and undergraduate mathematics appropriate to this. The course will also be accessible to students of applied mathematics.

515. Mathematics for Materials Science. (A)

Covers mathematics encountered in various problems encountered in materials science: Complex analysis and Fourier and Laplace transforms (used in diffraction and when solving differential equations). Linear transformations and tensors (continuum analyses of elastic, electric, etc. properties of crystals). Sturm-Liouville theory of linear differential operators (mathematics of quantum mechanics). Partial differential equations (wave, Laplace and diffusion equation).

520. Structure of Materials. (B) Prerequisite(s): Permission of the Undergraduate Curriculum Chair and Instructor.

Description of crystal structure and bonding. Symmetry: line, plane, point, and space groups. Symmetry considerations in structure-property relations. Physical optics, diffraction as Fourier transforms. Effects of size, shape, temperature and distortion on diffraction intensity. Gas, liquid, fibers, DNA. Diffuse scattering, order/disorder. Pair distribution function, inverse problem, small angle scattering. Radiation-matter interaction, scattering physics, atomic and electronic spectroscopy.

525. (ESE 525) Nanoscale Science and Engineering. (A) Prerequisite(s): ESE 218 or PHYS 240 or MSE 220 or equivalent, or by permission.

Overview of existing device and manufacturing technologies in microelectronics, optoelectronics, magnetic storage, Microsystems, and biotechnology. Overview of near- and long-term challenges facing those fields. Near- and long-term prospects of nanoscience and related technologies for the evolutionary sustension of current approaches, and for the development of revolutionary designs and applications.

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530. Thermodynamics and Phase Equilibria. (A) Prerequisite(s): Permission of the Undergraduate Curriculum Chair and Instructor.

Fundamental elements of engineering thermodynamics, statistical thermodynamics and materials thermodynamics. Covers thermodynamic functions, stability, phase transitions, mixtures (gases, condensed matter, polymer solution), defects and interfaces. Applications to energy problems (engines, efficiency, power, electrochemical cells), properties (constitutive equations, equation of states), phase diagrams and predominance diagrams.

536. ELEC PROP OF MATERIALS. (C)

555. Environmental Degradation of Materials. (B)

This course is designed to provide an understanding of the corrosion principles and the engineering methods used to minimize and prevent corrosion. Metals and alloys are emphasized because these are the materials in which corrosion is the most prevalent. Aqueous environments are also emphasized these are the common corrosion conditions.

In the first half of the course, the impact and electrochemical nature of the corrosion are described, and then the corrosion fundamentals (electrochemical reactions, phase (pourbaix) diagrams, aqueous corrosion kinetics, passivity, and high-temperature oxidation) are emphasized. The forms of corrosion (galvanic, pitting and crevice, environmentally induced cracking) and corrosion in the human body (for example, surgical implants and prosthetic devices) and in other selective environments (concrete, seawater, and water solutions containing dissolved salts, sulfur, and bacteria) are also described in the second half.

537. (MEAM537) Nanotribology. (C) Faculty.Prerequisite(s): Freshman physics; MEAM 354 or equivalent, or consent of instructor.

Engineering is progressing to ever smaller scales, enabling new technologies, materials, devices, and applications. This course will provide an introduction to nano-scale mechanics and tribology at interfaces, and the critical role these topics play in the developing area of nanoscience and nanotechnology. We will discuss how mechanics and tribology at interfaces become integrated with the fields of materials science, chemistry, physics, and biology at this scale. We will cover a variety of concepts and applications, drawing connections to both established and new approaches. We will discuss the limits of continuum mechanics and present newly developed theories and experiments tailored to describe micro- and nano-scale phenomena. We will emphasize specific applications throughout the course. Literature reviews, critical peer discussion, individual and team problem assignments, a laboratory project, and student presentations will be assigned as part of the course.

540. Phase Transformations. (B) Prerequisite(s): Permission of the Undergraduate Curriculum Chair and Instructor.

The atomic structure of condensed matter is dependent upon temperature, pressure, thermal history and other variables. In this course, the science of such structural transitions is treated. The topics discussed include introduction to statistical mechanics, theory of nucleation and growth kinetics, solidification, diffusionless solid state transformations, and microscopic theory of phase transition.

545. Materials for Energy Storage and Generation. (A)

This course provides an understanding of the major materials issues for current and emerging energy technologies. It includes a classification of materials for energy applications involving generation, transmission and storage of electricity; current and future uses of fossil fuels, with emphasis on higher efficiency uses of fossil fuels and "all electric" applications (e.g. transportation and power generation) and new materials as technology enablers for future energy sources: nuclear, fuel cells, solar, wind.

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561. (MEAM553) Atomic Modeling in Materials Science. (B)

This course covers two major aspects of atomic level computer modeling in materials. 1. Methods: Molecular statics, Molecular dynamics, Monte Carlo, Kinetic Monte Carlo as well as methods of analysis such as correlations, radial distribution function, etc. 2. Semi-empirical descriptions of atomic interactions: pair potentials, embedded atom method, covalent bonding, ionic bonding, tight-binding. Basics of the density functional theory. Needed mechanics, condensed matter physics, thermodynamics and statistical mechanics are briefly explained.

565. (MSE 465) Fabrication and Characterization of Nanostructured Devices. (C) Prerequisite(s): MSE 360 or permission of the instructor.

This course surveys various processes that are used to produce materials structured at the micron and nanometer scales for electronic, optical and chemical applications. Basic principles of chemistry, physics, thermodynamics and surface/interfacial science are applied to solid state, liquid, and colloidal approaches to making materials. The approaches to nano- and microfabrication: photolithography, soft lithography, nanoimprint lithography, 3D printing and self-assembly, are covered. The course is heavily lab based, with 25% of class time and 30% of the homework devoted to hands on experiences. Lab assignments are a series of structured individual/group projects. Evaluation is based on 3-4 lab reports, 4 problem sets with journal paper reading assignment, and a final project design.

570. (ESE 514) Physics of Materials I. (A) Prerequisite(s): Undergraduate physics and math through modern physics and differential equations.

Failures of classical physics and the historical basis for quantum theory. Postulates of wave mechanics; uncertainty principle, wave packets and wave-particle duality. Schrodinger equation and operators; eigenvalue problems in 1 and 3 dimensions (barriers, wells, hydrogen, atom). Perturbation theory; scattering of particles and light. Free electron theory of metals; Drude and Sommerfeld models, dispersion relations and optical properties of solids. Extensive use of computer-aided self-study will be made.

571. (ESE 515) Physics of Materials II. (M) Prerequisite(s): MSE 570 or equivalent.

Failures of free electron theory. Crystals and the reciprocal lattice wave propagation in periodic media; Bloch's theorem. One-electron band structure models: nearly free electrons, tight binding. Semiclassical dynamics and transport. Cohesive energy, lattice dynamic and phonons. Dielectric properties of insulators. Homogeneous semiconductors and p-n junctions. Experimental probes of solid state phenomena; photoemission, energy loss spectroscopy, neutron scattering. As time permits, special topics selected from the following: correlation effects, semiconductor alloys and heterostructures, amorphous semiconductors, electro-active polymers.

590. Surface and Thin Film Analysis Techniques. (M)

The objective of this course is to study the fundamental physics of the interaction of ions, electrons, photons, and neutrons with matter. A second objective is to use the products of these interactions to characterize the atomic (or molecular) structure, composition, and defects of a semiconductor, ceramic, polymer, composite, or metal. Ion beam techniques will include Rutherford backscattering and forward recoil spectrometry, and secondary ion mass spectrometry. Electron probe techniques will include x-ray photoelectron spectroscopy. Neutron techniques will include neutron reflectivity. The strengths and weaknesses of each technique will be discussed. Examples will be drawn from metallurgy, electronic materials, polymer science, ceramic science, archaeology, and biology.

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575. Statistical Mechanics. (B)

This course will provide an overview of select topics in equilibrium and non-equilibrium statistical mechanics. The emphasis will be on elucidating the basic postulates of statistical mechanics, explaining its fundamental laws and introducing the methodology of non-equilibrium processes via select applications in diverse fields. Statistical Mechanics is a unique branch of physics that permeates our understanding of matter at all length scales, from nanometers to stellar dimensions, and ranging in temperatures from nano-Kelvin to billions of degrees Kelvin. The techniques of Statistical Mechanics have been employed in condensed matter physics and materials science when studying solids, liquids, and gases as well as in other disciplines such as biology, zoology, molecular biology, physiology, economics, signal transmission and large scale networks such as the world-wide web. It is envisaged that students at Penn and especially in MSE/SEAS will benefit by getting a perspective of this fascinating subject and appreciate how its principles govern phenomena as diverse as semiconductor devices, greenhouse effect, biological pattern formation and instabilities on material surfaces.

580. (MSE 430) Polymers and Biomaterials. (A) Prerequisite(s): MSE 260 or equivalent course in thermodynamics or physical chemistry (such as BE 223, CHE 231, MEAM 203).

Polymer is one of the most widely used materials in our daily life, from the rubber tires to clothes, from photoresists in chip manufacturing to flexible electronics and smart sensors, from Scotch tapes to artificial tissues. This course teaches entry-level knowledge in polymer synthesis, characterization, thermodynamics, and structure-property relationship. Emphasis will be on understanding both chemical and physical aspects and polymer chain size/dimension that drive the molecular, microscopic and macroscopic structures and the resulting properties. We will discuss how to apply polymer designs to advance nanotechnology, electronics, energy and biotechnology. Case studies include thermodynamics of block copolymer thin films and their applications in nanolithography, shape memory polymers, hydrogels, and elastomeric deformation and applications.

581. Advanced Polymer Physics. (M) Prerequisite(s): MSE 430 or equivalent.

Advanced polymer physics includes the topics of polymer chain statistics, thermodynamics, rubber elasticity, polymer morphology, fracture, and chain relaxation. Rigorous derivations of select theories will be presented along with experimental results for comparison. Special topics, such as liquid crystalline polymers, blends and copolymers, will be presented throughout the course. Special topics, such as liquid crystallinity, nanostructures, and biopolymer diffusion, will be investigated by teams of students using the current literature as a resource.

597. Master's Thesis Research. (C)

599. Master's Indep Study. (C)

610. Electron Microscopy. (M)

Theoretical and practical aspects of conventional and high-resolution transmission electron microscopy and related techniques. Imaging theory; kinematical and dynamical diffraction theory. Diffraction contrast analysis of imperfect crystals; phase contrast analysis of crystal lattice structures. With laboratory.

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637. (MEAM637) Mesoscale Modeling and Simulation. (C)

This course is targeted at engineering, physical science, computational and mathematics Ph.D. students. The course focuses on techniques for the simulation/modeling of materials on a time and/or length scale that is large compared with atomistic/molecular but with structure that is fine on the scale of typical (homogenized) continuum theory. The course explores kinetic models, defect dynamics, and statistical mechanics models and their implementation in computer simulation.

650. (MEAM650) Mechanics of Soft and Biomaterials. (M)

This course is aimed to expose the students to a variety of topics in mechanic materials via discussion of "classic" problems that have had the widest impact long period of time and have been applied to analyze the mechanical behavior a variety of biological and engineering materials.

670. Statistical Mechanics of Solids. (M)

This course constitutes an introduction to statistical mechanics with an emphasis on application to crystalline solids. Ensemble theory, time and ensemble averages and particle statistics are developed to give the basis of statistical thermodynamics. The theory of the thermodynamic properties of solids is presented in the harmonic approximation anharmonic properties are treated by the Mie-Gruneisen method. Free electron theory in metals and semiconductors is given in some detail, with the transport properties being based on conditional transition probabilities and the Boltzmann transport equation. The theory of order-disorder alloys is treated by the Bragg-Williams, Kirkwood and quasi-chemical methods.

790. Selected Topics in Materials Science and Engineering. (C) Staff. Both terms

Students should check department office for special topics.

895. Teaching Practicum.. (C)