

MATERIALS SCIENCE AND ENGINEERING (MATSE)

MATSE 501: Thermodynamics of Materials

3 Credits

MATSE 501 Thermodynamics of Materials (3) The goal of this course is to teach the fundamental principles of thermodynamics of materials from a practical viewpoint - thermodynamics as a "toolbox" to help understand chemical behavior of materials. It attempts to integrate chemistry, phase equilibria, and thermodynamics of a materials system as different means of describing the same chemical behavior. It develops quantitative relationships among them. Thermodynamic terms/values are defined in terms of measurable quantities such as temperature, pressure (partial pressures), and concentrations to diminish the abstract nature of thermodynamics. The course emphasizes problem solving, and more specifically, developing explanations and understanding of chemical and thermal behavior observed in the laboratory/industry. A integral part of the course is to teach the use of state-of-the-art equilibrium thermodynamics computer software as an aid in performing calculations, particularly those involving chemically complex systems with many species.

Prerequisite: MATSE401 or equivalent

MATSE 503: Kinetics Materials Processes

3 Credits

This course covers fundamentals of atomistic theories and phenomenological descriptions of kinetic processes in solids. It provides the foundation for the advanced understanding of materials processing, phase transformations, and microstructural evolution. Topics include atomistic mechanisms of diffusion, solutions to the phenomenological diffusion equation, diffusion along extended defects, gas-solid reactions, phase transformations, computer simulation of diffusional processes, and microstructure evolution.

Prerequisites: CHEM 450 or GEOSC 521 or MATSC 501

Cross-listed with: CMPMT 503

MATSE 504: Solid State Materials

3 Credits

The main course objective is to present fundamental concepts and models to develop students' quantitative understanding of mechanical, electrical, optical, and thermal phenomena in solid-state materials. Emphasis is placed not only on the discussion of material properties, but also on building a comprehensive understanding of how structure affects properties in solid state materials and vice versa. An overview of quantum mechanics is given and applied to understanding confinement effects and their implication for electronic and optical properties in nanostructured materials. It is further used to provide a solid foundation for understanding LCAO, MO theory, and tight binding approximations as powerful tools towards a modern understanding of structure property relationships in materials science, bridging all the way from the atomic scale of structure to macroscopic scale of properties. The course content is reinforced by utilizing interactive simulation programs. The structure and physical properties of most solids can be understood from fundamental building blocks developed in the last century, namely, crystal

structure and symmetry of the organization of atomic nuclei in a solid, and the organization of electrons throughout this periodic Coulombic potential generated by the nuclei in a crystal. These are the essential concepts that will be emphasized in this course. It will begin with a description of crystal structure and diffraction theory to understand the crystal structure in real and momentum spaces in the form of a review. This will be followed by classical and semi-classical description of solids beginning from the free electron theory in metals, to tight binding theory in insulators, and band structure in semiconductors. Examples are given for how these different materials are employed in modern electronics and optoelectronics. One of the unique aspects of this course is that computer simulations will be used to aid in "visualizing" the concepts learnt in the class to develop an intuitive understanding of the structure in solid-state materials and their properties. The goal of the course is to equip the student with the knowledge necessary to master the modern framework in solid state materials that describes phenomena, such as electronic band structure, electronic transport, and the vibrational and thermal properties of solid state materials at an atomic level, and to prepare them for higher level graduate courses. The course is suitable for anyone interested in the science and engineering aspects of materials.

MATSE 506: Interfacial Electrochemical Processes

3 Credits

Electrochemical processes play a pivotal role in the development of new energy storage devices, energy-efficient material separation processes, and corrosion-resistant materials. This course covers the thermodynamic and transport properties of electrochemical systems, electrochemical characterization techniques, and their application in materials research. The course gives students an overview of the fundamental principles of electrochemical cells and electrode reactions based on the thermodynamic and transport properties at the electrode-electrolyte interface. The course will begin with thermodynamics of electrode reactions both in aqueous and non-aqueous electrolytes (e.g., molten salts), including the measurement techniques and Pourbaix diagrams. Then, the course will progress to kinetic aspects of electrode reactions, followed by the electrochemical characterization methods to determine critical kinetic parameters (e.g., exchange current density, diffusivity, and Tafel constants) based on dc (e.g., controlled potential, controlled current, and cyclic voltammetry) and ac techniques (e.g., a.c. voltammetry and impedance spectroscopy). Throughout the course, the application of electrochemical principles in modern materials research and processes will be covered, including electrochemical separation processes (e.g., electroplating, electrowinning, and electrowinning cells) of energy materials, evaluation of corrosion-resistant alloys, and electrochemical power sources (e.g., batteries and fuel cells).

PREREQUISITE MATSE 401 MATSE 402

MATSE 507: Biomaterials Surface Science

3 Credits

Special properties of surfaces as an important causative and mediating agent in the biological response to materials. BIOE 517 BIOE 517. (MATSC 517) Biomaterials Surface Science (3) This course will factor the classical picture of the biological response to materials into spatial and temporal components, identifying the special properties of surfaces as an important causative and mediating agent. Emphasis will be on biophysical mechanisms and the biological response to materials. Contact activation of blood plasma coagulation cascade, bioadhesion, and protein adsorption will be repeatedly used as example biological response to materials surfaces to illustrate concepts and principles.

Leading theories attempting to correlate both kinds of intensity of biological responses to surface and interfacial energetics will be compared and contrasted through a process that will quantify important surface thermodynamic properties of materials. The hydrophobic effect and related phenomena, especially as this pertains to water solvent effects in biology, will receive special emphasis. A general background in chemistry and/or biology is required, but prerequisites are purposefully limited, reflecting the interdisciplinary aspects of the subject and to draw students from different specializations.

Cross-listed with: BIOE 517

MATSE 508: Biomedical Materials

3 Credits

Properties and methods of producing metallic, ceramic, and polymeric materials used for biomedical applications. BIOE 508 BIOE (MATSE) 508 Biomedical Materials (3) The topical content of this course will be grouped into 4 areas. A general introduction to selected aspects of physiology will be presented. This will provide the background necessary to appreciate the factors which govern the selection of biomedical materials. Specific emphases will be placed on the polymerization of biopolymers (polypeptides and polysaccharides) and the general relationships between conformation and biological function, the biochemistry of blood and blood surface interactions, the formation of teeth and bone and the relationships between microstructure, composition and function, the immune responses to implanted materials, the resorption of bone (osteoporosis), and the development of caries. The perspective placed on these topics will be that of materials science. The selection of ceramics for hard tissue prosthesis will be described. Orthopaedic and dental applications for ceramics will be discussed. Specific ceramic materials to be treated include dental porcelain, alumina- and zirconia-based ceramics, and bioglasses. Various classes of inorganic cements, gypsum, zinc phosphates, zinc carboxylates, silicates, and glass-ionomer cements will also be considered as ceramics. Hydroxyapatite, HAp-based composites and HAp-metal interactions will be discussed in particular. Relationships among physical properties, mechanical properties, and chemical interactions with biological fluids will be described. Dental and orthopaedic applications of metals will be described. The fracture toughness of metals, their electrochemical responses in vivo, and the nature of the interfacial interactions with hard tissues will be treated. Dental amalgams and the noble metals for dental applications will be considered. Metals and alloys, such as Ti, Co-Cr, and stainless steel used in prosthetic applications will be described and their properties and limitations discussed. The phenomenon of stress shielding and the immune responses associated with the accumulation of metallic and polymeric particulate debris in the vicinity of an implant will be discussed in particular. Polymeric materials are important in a broad range of biomedical applications. Among these are soft tissue prostheses, hemostatic agents, dental restoratives, bone replacement materials, and surgical adhesives. In some applications, it is desirable that a polymeric material biodegrade while in others property retention is desirable. Because of the spectrum of applications for polymers, the topics to be covered will be limited with the intent to concentrate on hemocompatible polymers, acrylics used as bone cements, polyethylene used as bearing surfaces in prostheses, and dental resins and bonding materials. Other relevant polymers and their applications will be discussed.

Cross-listed with: BIOE 508

MATSE 509: Materials Science for Drug Delivery

3 Credits

Drug delivery systems (DDS) are technologies that improve pharmacokinetics and biodistribution of drugs with the goal to enhance therapeutic efficacy and reduce side effects. Key to successful development of DDS is to design drug vehicles that can deliver controlled amounts of drugs to the sites of interest for required periods of time by overcoming the challenges due to the complexity of biological systems. With the evolution of materials science and nanotechnology, a wide variety of materials ranging from polymeric or inorganic nanomaterials, hydrogels, bioresponsive/biomimetic/bioinspired materials, and micro/nanofabricated devices have been developed to fulfill the need for achieving maximum therapeutic outcomes of pharmaceuticals. The course will be designed to present the importance of integrating the knowledge and technologies of materials science, engineering, chemistry, biology, medicine and life science to advance this interdisciplinary research field. In addition, it will discuss how the developed technologies provide innovative approaches to translate basic knowledge into healthcare technologies. For this purpose, the course will first focus on the principles of drug therapy, therapeutic targets and requirements for designing drug delivery systems. It will also cover the general aspects of interaction with materials with biological systems, including relationships between properties of materials and their interactions with proteins, blood, and cells, clearance of materials in the body, and strategies to design materials to avoid these foreign body responses. These points will be explained from the viewpoint of materials scientists, chemists, and engineers. The course will also discuss the applications of different types of materials for drug delivery, including polymeric nanomaterials, organic-inorganic hybrid materials, hydrogels and microfabricated devices. In this part of the course, the historical overview as well as recent research progress in this field will be discussed to explain the strategies and methodologies to develop new materials for a wide variety of therapeutics including chemotherapeutics, nucleic acids, proteins, bioimaging reagents, reactive oxygen species and gaseous signal transmitters. Furthermore, the course will discuss the current challenges in the drug delivery research field, and future directions. Throughout the course, recent research papers will be presented to discuss the on-going research in this field, and develop the ability to read scientific articles critically.

MATSE 510: Surface Characterization of Materials

3 Credits

Physical and chemical principles of characterization techniques widely used in materials science, chemistry and engineering. CHE 510 (MATSE) 510 Surface Characterization of Materials (3) Surface and interface characterization is an important subject in nanotechnology, heterogeneous catalysis, semiconductor processing, advanced functional materials, biomaterials, corrosion, environmental science, and tribology. This course will study the physical and chemical principles of representative characterization techniques widely used in these research areas. Topics covered in this course include surface chemistry and physics fundamentals, x-ray and electron-based spectroscopy, vibration spectroscopy, ellipsometry, microscopy with physical probes, and multivariate data analysis. Physical principles and practical applications will be studied through theoretical calculations, data analysis, and literature reviews.

Cross-listed with: CHE 510

MATSE 511B: Transmission Electron Microscopy

1 Credits

Principles and practice of transmission electron microscope operation. Students undertake individual projects.

Cross-listed with: GEOSC 511B

MATSE 512: Principles of Crystal Chemistry

3 Credits

Relation of structure to ionic size and nature; influence of pressure and temperature on structure; chemical-structural defects, crystalline solutions, phase-transitions. MATSE (GEOSC) 512 Principles of Crystal Chemistry (3) Crystal chemistry is concerned with the systematics of crystal structures as determined by ionic sizes and characteristics of chemical bonds and with changes in crystal structure with variations in temperature and pressure. The course begins with a short review of crystallography. It then proceeds to elements and ions as the building blocks of crystals. Models for the chemical bonds which bind elements and ions into crystals include classical electrostatic theory, crystal field theory, molecular orbital theory, and band theory. The principles underlying each model are explained. The next step in the buildup of crystals is to explain the principles of ionic packing, crystal defects, and the concepts of polymorphism and phase transitions. With the underlying principles and theory in place, the second half of the course deals with a systematic presentation of the various families of crystal structures, their properties, and some indication of the practical utilization of the various structural families. The discussion proceeds from binary packing structures to packing structures of ternary and quaternary composition, to metal structures, to silicate structures, to organic crystals, to defect structures and non-crystalline solids. The course is divided into seven parts, and grading is achieved by a 30-minute quiz following completion of each part. There is no suitable textbook, but a comprehensive set of printed notes is provided as are recommended readings of selected review articles and current literature. Students are also required to prepare a semester paper on a topic of their choice.

MATSE 514: Characterization of Materials

3 Credits

Classical and new (microprobe, scanning microscope, magnetic resonance, and Mossbauer) techniques for the characterization of composition, structure, defects, and surfaces. MATSE 514 Characterization of Materials (3) This course is designed for graduate and selected undergraduate students. The broad spectrum of the various materials characterization techniques will be briefly surveyed. Students will not be taught how to run specific instruments or be expected to be an expert on the analytical techniques. However, students will be given assignments that require a search of the literature and having discussions with the relevant experts to develop a detailed understanding of specific characterization techniques. Students will also be required to apply statistical methods in their assigned projects. The objectives of the course include the presentation of a survey of material characterization techniques, lectures on experimental design and use of statistical techniques, as well as problem-solving techniques. The goal is to provide students with a foundation in the use of characterization techniques to solve and diagnose material problems that can be identified and potentially resolved with materials characterization. The first part of the lectures provides a survey on many of the material characterization techniques. The second part of the course covers statistical analysis of

experimental data including small population statistics, error analysis, curve fitting routines, and a brief survey of statistical experimental design. The third part of the course covers problem-solving techniques using materials characterization. Several characterization problems are given to the class that require the formation of project teams composed of 4 to 5 class members to resolve. Each project team prepares oral and written reports for the problem selected.

MATSE 520: Polymer Science and Engineering

3 Credits

This course provides fundamental understanding of basic principles in polymer science and connects these to current research topics at Penn State as well as novel findings in soft material science at other institutions. Interdisciplinary in content, the curriculum spans from polymer synthesis (chemistry), to physical properties (physics), to characterization, to engineering (chemical engineering), to application of polymer materials (materials science). Two areas of focus will lie on (i) the environmental impact of commodity plastics and (ii) conductive polymers and their every-day use in display technology and energy harvesting. While polymers are versatile and broadly applicable, there lie significant dangers in their use for us as a society. For example, while the drive for flexible displays and solar cells is increasing, there is no clear pathway for efficient recycling of the resulting electronic polymeric materials. To this end, this course will engage students in discussions about industrial processing of polymers and the importance to find new pathways for their recycling.

Cross-listed with: CHE 520, CHEM 520

MATSE 523: Environmental Degradation of Materials in Nuclear Power Plants

3 Credits

Degradation of materials performance when exposed to the combination of high temperature, neutron irradiation, and aggressive electrochemistry found in nuclear reactors.

Prerequisite: MATSE409

Cross-listed with: NUCE 523

MATSE 525: Communicating Topics in Materials Science

3 Credits

This course is designed to expand students' knowledge of materials science, engineering, and research. The course will cover the properties and applications of a broad range of materials based on each student's proposed research topic. Students will develop an understanding of the primary characterization methods that are used to study and measure the physical and chemical properties of the chosen material and how to appropriately communicate research ideas to their peers. Additionally, students will learn about the broader impacts of their work and the importance of broadening participation - each of which are required elements in NSF proposal.

MATSE 530: X-Ray Crystallography and Diffraction

3 Credits

Reciprocal lattices and the Ewald sphere construction; crystal structure determination by powder and single crystal techniques; space groups. MATSE 530 X-Ray Crystallography and Diffraction (3) MATSE 530 is a general introduction to the crystallography and x-ray diffraction for a

variety of different studies of the structure of solids. Students will gain an understanding of basic crystallography, the geometry of diffraction measurements and instrumentation, and the interpretation of diffraction data. Diffraction studies using synchrotron radiation and neutrons are also discussed.

Prerequisite: MATSE430

MATSE 531: Transmission Electron Microscopy

3 Credits

Diffraction pattern analysis and simple contrast theory applied to the structures of materials; analytical techniques in the microscope. MATSE 531 Transmission Electron Microscopy (3) This course will present the fundamentals of elastic and inelastic electron beam interactions with solid-state materials. Students will learn theoretical and practical aspects of electron diffraction and imaging, energy-dispersive x-ray spectroscopy, and electron energy loss spectroscopy. They will learn how to apply this knowledge to conduct experiments in and interpret data from the transmission electron microscope.

MATSE 534: Advanced Solidification Processes in Metallic Materials

3 Credits

The emergence of advanced manufacturing processes, such as additive manufacturing, has introduced high levels of uncertainty in well-established process - structure - property- performance relationships. A comprehensive understanding of solidification across spatial and temporal scales is needed in order to identify the underlying phenomena driving these unique structures and properties. In this course, the processes driving solidification and the properties of liquid metals will be covered to provide a framework for understanding more complex solidification processes in multi-component systems. Building on a fundamental understanding of both the thermodynamics and kinetics of solidification processes, the properties of interfaces and nucleation and growth will be studied across a range of material systems, including those exhibiting eutectic and peritectic transformations. With this basic knowledge, the role of complex processing conditions and their impact on multi-component alloy systems will be investigated for conditions prevalent in advanced manufacturing processes and correlated with advanced and emerging characterization tools.

Recommended Preparation: Students in this course should have a basic understanding (undergraduate level) of physical metallurgy principles, including solidification, solid-state phase transformations, heat treatment, and thermomechanical processing.

Cross-listed with: ESC 534

MATSE 535: Geometrical Crystallography

3 Credits

Derivation of lattices, types, point groups, and space groups; and group theory applied to crystallography and spectroscopy. MATSE 535 Geometrical Crystallography (3) Visual, mathematical, and group theory approaches are used to examine in detail the geometry of periodic, quasiperiodic, and incommensurate structures. From computer-assisted class discussions and weekly homework assignments, the student becomes familiar with the symmetry operations involved in translation, rotation, and color changes. Point groups, space groups, and color groups are derived through a combination of visual and mathematical

considerations. The structure of group theory is then explored and applied to the derivation of space groups.

MATSE 540: Crystal Anisotropy

3 Credits

Symmetry aspects of crystals and physical properties. Matrix and tensor methods. MATSE 540 Crystal Anisotropy (3) In this course symmetry and tensors are used to describe the physical properties of materials as a function of direction, i.e., how a material will respond to different types of stimuli as a function of direction. A variety of thermal, mechanical, electric, magnetic, and optical properties are covered, including pyroelectricity, pyromagnetism, thermal expansion, dielectric constant, magnetic susceptibility, piezoelectricity, piezomagnetism, elastic stiffness and compliance, electrostriction, magnetostriction, index of refraction, and non-linear optical effects. At first the response of single crystals are considered, but this is later extended to polycrystalline samples with various types of texture. As the course makes extensive use of symmetry, several weeks are dedicated to the development of the 32 crystallographic point groups using group theory. Symmetry operations are described using coordinate transformation matrices and stereographic projections. Both tensor quantities and tensor properties are described as a function of increasing tensor rank (up to fourth rank) for a multitude of polar tensors followed by axial tensors. For magnetic materials, the 90 magnetic point groups are introduced. For polycrystalline materials, the 7 Curie groups are utilized. A variety of practical examples illustrating the use of tensors to describe the properties of materials are covered in class and in in-depth homework sets involving both matrix and tensor form. The computer program Mathematica is used extensively in class and in the homework sets to visualize the physical properties of materials in three dimensions as well as to rapidly apply symmetry and tensor methods to high-rank tensor properties of low symmetry materials.

Prerequisite: PHYS 412

MATSE 542: Polymeric Materials: The Solid State

3 Credits

Introduction to the fundamental concepts necessary to understand solid state structure and properties of polymer materials. MATSE 542 Polymeric Materials: The Solid State (3) This course will cover concepts important to understanding polymer solids and their physical properties. We will begin with the concept of (partial) crystallinity, and the solid state microstructure of semi-crystalline polymers and copolymers. The fundamentals of crystallization kinetics of polymers will be covered, as will the concept of 'annealing'. Wide-angle x-ray diffraction and small-angle x-ray scattering methods will be discussed in the context of characterization of crystalline polymer structure. A discussion of nanoscale associations in both crystalline and non-crystalline ion-containing polymers will complete the first portion of the course. Several classes on the liquid crystalline state will follow, together with discussion of lyotropic and thermotropic liquid crystalline polymers. The fundamentals of binary and ternary polymer mixtures will come next. Concepts important to both miscible blends (e.g. concentration fluctuations) and immiscible blends (e.g. rubber toughening) will be covered. The origin of the morphology (phase diagrams) and properties of di-, tri- and multiblock copolymers will be discussed, as will their role as interfacial agents in multiphase systems. The latter portion of the course will be concerned with electrical and mechanical properties. The former will focus on dielectric relaxation, and conductivity (both electronic

and ionic). The latter will focus on the relationship between solid state structure and mechanical (including viscoelastic) properties.

Prerequisite: MATSE443 and MATSE445 or equivalent

MATSE 543: Polymer Chemistry

3 Credits

This graduate course discusses the new advances in polymer chemistry that leads to new polymeric materials with interesting structures and properties. CHEM (MATSE) 543
CHEM (MATSE) 543 Polymer Chemistry (3) This course provides advance level of polymer chemistry and materials taught in MATSE 441 - Polymeric Materials. Students are able to know the versatility that is inherent in polymer chemistry and the new research results and activities, especially controlling polymerization, polymer structures, designing polymers with desirable properties, etc. Students shall also understand the major economic and environmental concerns and solutions in producing commercial-scale polymers. This polymer chemistry course provides important links between chemistry and polymeric materials. The course will focus on recent advances in polymer chemistry that affords new polymer materials with controlled polymer structures, compositions, and properties, as well as economic and "green" processes. This course is designed for graduate students having basic knowledge in organic, inorganic, and organometallic principles. For Chemistry major, this course offers students with the knowledge to apply chemical principles and methods to design and prepare the desirable polymers (no prerequisite for Chemistry graduate students). For Material Science and other majors, this course provides advance level of polymer chemistry and materials taught in MATSE 441 (a prerequisite course). In addition, each student will be required to review (presentation and term-paper) a contemporary subject relative to polymer chemistry, which will help student self-education, and presentation and writing skills. Students will be evaluated by quizzes and examinations, a term-paper and presentation, and class participation.

Prerequisite: MATSE441 or approval of program
Cross-listed with: CHEM 543

MATSE 544: Computational Materials Science of Soft Materials

3 Credits

Pursue applications of computational modeling methods to soft materials; explore use of these methods to different research areas.

MATSE 545: Semiconductor Characterization

3 Credits

Physical principles and experimental methods used to characterize the electrical, optical, structural and chemical properties of semiconductor materials.

Cross-listed with: EE 545

MATSE 546: Advanced Metallic Material Feedstocks for Additive Manufacturing

4 Credits

Additive manufacturing (AM) processes use a variety of metallic material forms to produce complex components. These material forms can vary from metallic powders with a rather wide range of size distributions to metal wire to sheet and other more complex composite material types. Knowledge of the processing of these different feedstock forms along

with means to characterize them is needed to develop AM processes and procedures capable of being more widely used, particularly in critical applications. In this course, the production, handling, blending, and characterization of common metallic and composite feedstock materials will be covered. Feedstock forms to be addressed include metal and metal-ceramic composite powders, wire, and sheets, along with new product forms becoming available. A multi-disciplinary approach will be taken to elucidate the connections between production, characterization, and handling to develop an understanding of the role of feedstocks on the resulting process-structure-property relationships for AM processes and products.

Prerequisite: ESC 545 CONCURRENTS: MATSE 567, IE 527

MATSE 548: Dielectric and Other Electroceramics

3 Credits

Preparation and properties of ceramic semiconductors, dielectrics, and magnetic materials. MATSE 548 Dielectric & Other Electroceramics (3) This course reviews the fundamental underpinnings of electroceramic materials as used in passive, active, and sensor components, and systems. The recent literature and industrial trends are critically discussed within the course to aid students in identifying key material science problems to be solved in this area.

MATSE 552: Sintering of Ceramics

3 Credits

Design and interpretation of ceramic microstructures through an understanding of the physics and chemistry of sintering and grain growth. MATSE 552 Sintering of Ceramics (3) This course is about the processing of ceramic-based materials by sintering processes. Sintering is the thermal processing of a porous material which results in a decrease in surface free energy, strengthening and usually densification. The first half of the course covers the thermodynamics, mechanisms, kinetics, and models for densification. The theory of grain growth and coarsening processes are also discussed. The relations between densification and grain growth are discussed as they influence microstructure evolution. Tools for characterizing sintering and grain growth processes are reviewed. Practical applications of sintering for the manufacture of ceramic-based components ranging from low temperature co-fired ceramics to transparent ceramics are discussed.

Prerequisite: MATSE411

MATSE 555: Polymer Physics I

3 Credits

Introduction to the fundamental concepts needed to understand the physics applicable to polymer melts, solutions and gels. MATSE (PHYS) 555 Polymer Physics I (3) This course develops fundamental understanding of the conformations of polymers in solution and melt states. We start with ideal chains that have random walk statistics. Next excluded volume is introduced to understand the self-avoiding walk conformation and collapsed conformation of real chains. The behavior ideal and real chains are studied in extension, compression and adsorption. While positive excluded volume leads to swelling, negative excluded volume leads to collapse and phase separation. The phase behavior of polymer mixtures and solutions is described in detail. Semidilute solutions are understood in terms of two length scales where each chain changes its conformational statistics. Scattering is used to determine the conformation of chains, their molar mass and their

interactions with surroundings. Percolation theory is introduced to model the statistics of random branching and gelation. The rubber elasticity of fully developed networks is understood in terms of the stretching laws for network chains. Entanglement effects, swelling and viscoelasticity are discussed in detail. Once the conformations of polymers are understood, dynamics of polymer liquids are considered. In dilute solutions hydrodynamic interactions dominate and the viscoelasticity predicted by the Zimm model is derived. In unentangled melts of short chains, hydrodynamic interactions are screened and the Rouse model is used to understand viscoelasticity. Unentangled polymers in semidilute solutions have Zimm dynamics on small length scales and Rouse dynamics on longer length scales. Dynamic scattering techniques are discussed for measuring polymer dynamics. Entanglement effects are described using the tube model, where surrounding chains confine the motion of a given polymer to a tube-like region. The effects of concentration, chain length and polydispersity of linear chain polymer liquids are discussed in detail. The effects of branching on polymer dynamics are introduced at the level of simple structures such as star polymers and comb polymers. The course assumes some prior knowledge of polymers, usually obtained through an introductory undergraduate course. The students should attain a working understanding of the basic concepts of polymer physics in this course, allowing them to tackle more difficult problems in their research. Such skills are reinforced through homework and take-home examinations.

Cross-listed with: PHYS 555

MATSE 556: Polymer and Composite Materials for Additive Manufacturing

3 Credits

This course will focus on how polymers are used in 3D printing including topics of thermal processing, photopolymerization, composites, and modern topics at the intersection of polymer science and additive manufacturing. Of particular importance will be the description of how additive manufacturing processes influence the final properties of polymeric and composite materials. The details of polymer chemistry and material structure will be covered to give students foundational knowledge in materials and additive processes. Basic ASTM processes in additive manufacturing will be described along with hybrid processes and topics in modern research. This course will give students a competitive advantage in understanding both materials and new manufacturing processes. The unique aspects of additive manufacturing will be discussed in the context of manufacturing economics and its impact on polymer processing as the industry and the technology develops.

MATSE 560: Hydrometallurgical Processing

3 Credits

Fundamental physico-chemical factors underlying the aqueous extraction and recovery of metals and nonmetals from ores, minerals, and scrap metal. MN PR 507 (MATSE 560) Hydrometallurgical Processing (3) This 3-credit course is concerned with the fundamental physico-chemical processes associated with the processing, utilization, and recycling of materials in aqueous systems. The topics covered cut across a wide range of practical applications. The course is therefore suitable for a broad spectrum of scientists and engineers concerned with processes and processing in aqueous systems, e.g., in materials science and engineering, mineral processing, geoscience, soil science, environmental engineering, chemistry, chemical engineering, petroleum and natural gas engineering, mining engineering, nuclear engineering, and electronic and electrical engineering. A required term paper provides a formal

mechanism for ensuring that students have the opportunity to apply ideas discussed in the course to their specific areas of interest.

Prerequisite: MATSE426

Cross-listed with: MNPR 507

MATSE 564: Deformation Mechanisms in Materials

3 Credits

Deformation of crystalline/amorphous solids and relationship to structure; elastic, viscoelastic and plastic response over a range of temperatures and strain rates. EMCH 535 / MATSE 564 Deformation Mechanisms in Materials (3) The course will study the relationship between the deformation mechanisms in materials and their structure. The types of deformation behavior considered in the course are linear elasticity (isotropic or anisotropic), viscoelasticity and plastic deformation. For the elastic behavior, the emphasis will be on the way elastic behavior is controlled by atomic structure and microstructure. The constitutive laws that describe this behavior and the assumptions on which they are based will be introduced. The next phase of the course considers the range of deformation behavior from purely viscous (linear or non-linear) to viscoelastic. Initially, the emphasis will be on the effects of temperature and strain history and the way this behavior is described by mechanical analogs. The effect of structure on creep and stress relaxation will be described. The use of linear viscoelasticity in describing the sintering process will also be included. In ductile crystalline materials, deformation is associated with the movement of dislocations. The types of dislocations, their stress fields and energies will be described. These aspects will then be combined with structural features by including considerations of slip geometry and obstacles to dislocation motion. This approach will allow strengthening methods to be identified and quantified. Finally, creep mechanisms in crystalline materials at high temperature will be discussed and quantified.

Prerequisite: E SC 414M or MATSE436

Cross-listed with: EMCH 535

MATSE 565: Metals in Electronics

3 Credits

Processing and performance of metals in electronics, covering electrical resistivity, metal film deposition, metal/semiconductor contacts, interconnects, and electronic packaging. MATSE 565 Metals in Electronics (3) This course addresses the processing, use, and performance of metals in electronics. The course is intended to provide students with a background in semiconducting or other electronic materials with specific knowledge about the application of metals in electronics as well as to allow students with a metallurgical background to learn about how their expertise fits into the electronics industry. Topics covered include electrical resistivity in thin metal and alloy films, deposition of thin metal films, metal/semiconductor contacts, interconnects in microelectronics, electromigration, diffusion barriers, electronic packaging, and metal/metal contacts. Grades are based on homework problems, a term paper, and class presentations. The course is offered in alternate fall semesters.

MATSE 567: Additive Manufacturing of Metallic Materials

3-4 Credits

This course will expose students to the state of the art in understanding processing, structure, and property relationships in materials fabricated using additive manufacturing (AM). There will be a strong focus on

metallic alloys, but polymers, ceramics, and advanced materials will also be briefly discussed. The emphasis of the course will be on understanding the links between processing and the resulting structure, as well as the microstructure and the mechanics of the fabricated materials. Initially, we will discuss the types of AM and the feedstock materials required for these processes. We will then focus on metals, and discuss the energy sources used in AM (lasers, electron beams), and their interactions with the material. We will discuss the molten pool characteristics and the solidification microstructures. We will relate the microstructures seen in AM to the resulting mechanical properties (elastic deformation, plastic deformation, fracture, fatigue performance, and residual stress/distortion). Finally, we will discuss specific case studies for metals, polymers, ceramics, and advanced materials.

Cross-listed with: AMD 567

MATSE 570: Catalytic Materials

3 Credits

Preparation and characterization of solid catalytic materials and the relationships between their surface, defect, and electronic properties and catalytic activity. MATSE (EME) 570 Catalytic Materials (3) This course covers the preparation and characterization of solid catalytic materials, and the relationships between the surface and electronic properties and pore structure of the materials and their catalytic activity and selectivity. The course includes the following materials: zeolites and molecular sieves; metals and alloys; metal oxides; metal sulfides; and other catalytic materials. Also included are the major applications of catalytic materials in chemical and petroleum industries and in other manufacturing industries for environmental protection. This course can be grouped into three parts: (1) introduction to catalysis and analytical techniques; (2) synthesis and characterization of catalytic materials; and (3) catalysis at surfaces of solid materials. The course is suitable for a broad spectrum of students in energy and mineral engineering, materials science and engineering, fuel science, chemical engineering, chemistry, solid-state science, and environmental engineering.

Prerequisite: CHEM 452 or similar course in chemical, materials or energy sciences and engineering

Cross-listed with: EME 570

MATSE 575: Functional Polymeric Materials

3 Credits

In-depth discussions of structure/property relationships in functional polymers and modern concepts of structural design of polymers.

MATSE 580: Computational Thermodynamics

3 Credits

The integration of fundamental principles and advanced computational approaches in the thermodynamics of materials, including hands-on computation, theory and application.

Prerequisite: MATSE501 or equivalent

MATSE 581: Computational Materials Science II: Continuum, Mesoscale Simulations

3 Credits

This course will focus on computational techniques and fundamentals of phase transformation simulations on the continuum, mesoscale level.

MATSE 581 Computational Materials Science II: Continuum, Mesoscale Simulations (3) This course will focus on computational techniques and fundamentals of phase transformation simulations on the continuum, mesoscale level. The objective of the course is to introduce the evolution of simulation techniques and integrate fundamental principles in thermodynamics and kinetics with advanced computational approaches. The teaching will be problem-oriented using literature publications. There will be many hands-on computer exercises to gain experience in presenting problems to computer and interpreting the computer results. This course is particularly useful for students who would like to explore the power of computational approaches and would like to understand the thermodynamic and kinetic principles behind computational phase transformations.

Prerequisite: MATSE501 and MATSE503

MATSE 582: Materials Science and Engineering Professional Development

1 Credits

This course covers ethical conduct of research, pathways of professional development and strategies and tools for research.

MATSE 590: Colloquium

1 Credits/Maximum of 1

Continuing seminars which consist of a series of individual lectures by faculty, students, or outside speakers.

MATSE 596: Individual Studies

1-9 Credits/Maximum of 9

Creative projects, including nonthesis research, which are supervised on an individual basis and which fall outside the scope of formal courses.

MATSE 597: Special Topics

1-9 Credits/Maximum of 9

Formal courses given on a topical or special interest subject which may be offered infrequently.

MATSE 597B: **SPECIAL TOPICS**

1-3 Credits

Cross-Listed

MATSE 600: Thesis Research

1-15 Credits/Maximum of 999

No description.

MATSE 601: Ph.D. Dissertation Full-Time

0 Credits/Maximum of 999

No description.

MATSE 602: Supervised experience in college teaching

1-3 Credits/Maximum of 6

Supervised assistance with the teaching program in metallurgy. MATSE 602 Supervised Experience/College Teaching (1-3) This course

provides the opportunity for graduate students to learn college teaching by assisting a faculty member with an undergraduate or graduate course.

MATSE 801: Foundations in Materials Science for the Professional Engineer

3 Credits

Materials science is ubiquitous. All modern industry is highly dependent on materials whose properties can be controlled or engineered to accommodate a wide range of applications. The multidisciplinary field of materials science and engineering outlines approaches to enhance the manipulation of existing materials and synthesis of new materials. Further, the study of materials science and engineering provides the basis for understanding material properties with respect to chemistry and atomic structure and specifically the ability to tailor chemistry and structure in order to bring about specific properties (materials by design). Finally, an understanding of materials from a structure-processing-properties point of view allows for troubleshooting of modern manufacturing with respect to materials outcomes. Students will investigate why particular materials perform with specific properties while other materials do not. Students will then investigate how materials can be manipulated to perform actions that are typically not expected from a particular material. The previous two investigations will then allow students to begin to create materials by design to serve in specific industrial and environmental settings. All of these actions will be supported by the student's acquired knowledge of the role of fundamental chemistry, physics and math in describing, measuring, and predicting materials performance.