

## **MSE GRADUATE PROGRAM - Course Descriptions**

**MSE 2001 Statistical Physics of Materials (3 credits)** Quantum theory of matter; wave mechanics; kinetic theory; statistical mechanics; statistical thermodynamics; phase space and ensembles; canonical and microcanonical ensembles; fluctuations; statistical mechanics of crystals; free electron theory of metals; cooperative phenomena; statistical mechanical theory of rate processes.

**MSE 2002 Solid-State Theory in Materials Science (3 credits)** Diffraction by crystals; symmetry; lattice waves; lattice vibrations and thermal properties; band theory of solids; theory of the metallic state; transition metals; semiconductors; optical properties; electronic structure of solids; ferromagnetism; magnetic properties of matter; magnetic materials and technical magnetics; domain theory; superconductivity.

**MSE 2003 Structure of Materials (3 credits)** Basic crystallography of materials; symmetry; point groups and space groups; tensor properties of crystals; diffraction methods in materials science; atomic packing and structures; glassy state, polycrystalline aggregates; grain boundaries and interfaces in materials; textures; multiphase materials; quantitative stereology and microstructural characterization; thin films.

**MSE 2004 Advanced Dislocation Theory (3 credits)** Origin, geometric aspects, and types of dislocations; experimental evidence; theoretical strength of crystals; elastic properties, stress field, and strain energy of dislocations, interaction with other dislocations and lattice imperfections; dislocations in particular crystal structures; dislocation reactions, the structure of crystal boundaries; applications.

**MSE 2005 Point Defects in Crystalline Solids (3 credits)** This course is concerned with point defects in metals, alloys, elemental semiconductors and inorganic compounds. The various types of point defects in such materials are described and are effects of different parameters, such as temperature and impurities, on defect concentrations are examined. Examples of defect dependent processes, such as diffusion, ionic and electronic conductivity, oxidation, and sintering are described. Surface and interface effects on defect concentrations are then discussed. Finally, technical applications of solid electrolytes and solid-state ionics as sensors, batteries and fuel cells are discussed.

**MSE 2009 Computer Applications in Materials (3 credits)** A variety of numerical techniques are discussed, including solution of transcendental equations, integration, matrix manipulation, solution of simultaneous equations, and use of finite difference and finite element methods for solution of partial differential equations. Specific computer topics demonstrated include graphics modeling and use of the digitizer. Materials applications covered include heat and fluid flow analyses for metals and polymers, diffusion, and metalworking die and perform design.

**MSE 2011 Energetics (3 credits)** Advanced classical thermodynamics; chemical equilibrium solution thermodynamics; quasichemical model; electrochemical cells;

surface tension; thermodynamics of interfaces; introduction to thermodynamics of irreversible processes.

**MSE 2013 Kinetics in Materials Science (3 credits)** Basic concepts in the theory of rate processes; activation energy; chemical reaction kinetics; temperature dependence of reaction rates; statistical mechanical basis for the theory of rate phenomena; absolute reaction rate theory; thermodynamics of irreversible processes; diffusion in materials; mechanisms of atomic migration; gas-solid reactions; kinetics of phase transformations; interface migration kinetics; thermally activated deformation processes.

**MSE 2014 Phase Transformations (3 credits)** Energetics of transformations; stability criteria; classification of transformations; theory of rate processes; classical nucleation theory; liquid-solid transformations; precipitation from solid solution; spinodal decomposition; metastable phases; transition phases and GP zones; growth of phases; interfacial stability; eutectoid decomposition; massive transformations; martensitic transformations; order-disorder phenomena; nucleation in glass-forming systems; phase separation in glasses; metastability in glass; and glass-ceramics.

**MSE 2015 Electromagnetic Properties of Materials (3 credits)** Basic principles governing the electrical, magnetic, and optical properties of engineering materials; semiconductor devices; dielectrics; ferroelectrics; technical magnetic properties; hysteresis behavior; applications of hard and soft magnetic materials; superconductivity; high temperature ceramic superconductors; electro-optical materials and devices.

**MSE 2030 Mechanical Behavior of Materials (3 credits)** Continuum mechanics concepts; stress, strain, tensor notation, and equations of equilibrium; comparison of materials behavior: bonding, structure and properties of metals, ceramics, and polymers; constitutive relations: linear and non-linear elasticity, and plasticity; time-dependent deformation: visco-elasticity, mechanical analogs, vibrations and damping, anelasticity, creep, stress-rupture, and deformation mechanism maps; fracture under monotonic loading conditions: brittle, ductile, ductile-to-brittle transition, role of structure, role of stress state, fracture mechanisms, fractography, fracture mechanics, notched-bar impact test, methods of increasing resistance to brittle and ductile fracture; fracture under cyclic loading conditions: fatigue testing, statistical treatment of failure data, S-N curves, strain-life diagrams, low and high-cycle fatigue, and materials/component design concepts for increased resistance to fatigue failure.

**MSE 2031 Metal-Forming Processes (3 credits)** Mechanical fundamentals: stress, strain, strain-rate, yield criteria, stress-strain relations, strain energy, friction, limit analysis; metal-forming processes considered with respect to practices, analyses, and interrelationships between practice and theory; metal-forming processes covered include forging, rolling, wire drawing, extrusion (direct and hydrostatic), and sheet-forming operations.

**MSE 2032 Failure of Materials (3 credits)** Principles of continuum mechanics

and physical metallurgy are applied in the fundamental description of failure in metals, ceramics, and polymers. After a brief review of the concepts of stress, strain, modes of failure, and fractography, in-depth study is made of fracture mechanics, fatigue failure, fretting, wear, creep, shock loading, and corrosion-assisted failures. Case studies are given throughout to illustrate the methods of load and stress analysis combined with fractography.

**MSE 2033 Magnetic Properties of Materials (3 credits)** Magnetic properties of matter; ferro-, ferri-, and anti-ferromagnetism; diamagnetic and paramagnetic substances; magnetostatics; the fundamental quantities in the description magnetic behavior; measurement of magnetic quantities; hysteresis; magnetic domains; magnetic anisotropy; magnetostriction; permeability; coercivity; and hard and soft magnetic materials for engineering applications; thin film and fine-particle behavior.

**MSE 2035 Advanced Physics of Materials (3 credits)** Diffraction by crystals; crystal symmetry; lattice waves; lattice vibrations and thermal properties; free electron theory of metals; band theory of solids; transition metals; insulators and semiconductors; superconductivity; ferroelectrics; optical properties of solids.

**MSE 2036 Introduction to Continuum Mechanics (3 credits)** The fundamental concepts of continuum mechanics necessary for studying the mechanical behavior of solids and fluids. Included a review of vectors and tensors; stress; strain and deformation; general principles in the form of balance laws; constitutive equations and their restrictions; and specialization to the theories of linearized elasticity and fluid mechanics.

**MSE 2037 Nanomechanics, Materials and Device (3 credits)** This course is an introduction for current nanotechnology and fundamentals for nanoengineering. It mainly contains three areas: nanomechanics, nanomaterials and nanoscaled devices. In nanomechanics, it covers nanoindentation mechanics, thin film mechanics and one dimensional nanowire mechanics, nanocrack mechanics, deformation in nanomaterials. Nanomechanical model will be emphasized in nanomaterials, it covers carbon nanotube, one dimensional semiconducting nanowires and nanomultilayers as well as nanostructured composites. Novel property/phenomena reviewed.

**MSE 2038 Applied Solid Mechanics (3 credits)** Stress and strain transformations; applied elasticity problems in torsion and plane problems; thermal stresses and elementary plasticity; energy methods; fundamentals of finite element methods.

**MSE 2041 Advanced Physical Metallurgy 1 (3 credits)** The cold-worked state: point defects, dislocations, crystal plasticity, work hardening, stored energy; dynamic restoration processes: dynamic recovery, dynamic recrystallization, and postdynamic recrystallization; static restoration processes: static recovery, static primary recrystallization; deformation and restoration of two-phase alloys; grain coarsening behavior: normal, abnormal (secondary recrystallization), and tertiary recrystallization; genesis of preferred orientation: inverse and full pole figures, crystallite orientation distribution functions, deformation textures, and

recrystallization textures.

**MSE 2042 Advanced Physical Metallurgy 2 (3 credits)** Strengthening mechanisms in metals and alloys; theoretical strength of crystals; particle strengthening; dislocation-particle interactions; grain size strengthening; strengthening by presence of grain boundaries; Hall-Petch expression; theories of discontinuous yielding; solid-solution strengthening; fiber strengthening and the design of high-strength microstructures.

**MSE 2043 Electron Microscopy in Materials Science (3 credits)** Electron optics, lens aberrations, depth of field, depth of focus, resolution, contrast, bright and dark field microscopy, selected area diffraction, calibration, specimen preparation, electron scattering, electron diffraction, Bragg's law, Laue conditions, structure factor, Ewald construction, double diffraction, twinning, Kikuchi lines, contrast theory, kinematical theory of diffraction by perfect and imperfect crystals, limitations, column approximation, extinction contours, dynamical theory, special techniques, high voltage microscopy, applications.

**MSE 2044 Scanning Electron Microscopy & EPMA (3 credits)** This course is designed to introduce the students to the SEM and associated techniques in particular electron probe microanalysis (EPMA). It will also give an understanding of SEM and EPMA so that users can make the most of these techniques. The course will include demonstrations on a state of the art field emission microscope. Major topics are: Interaction of electrons with solids, Electron optics, Image formation in the SEM, X-ray microanalysis (qualitative and quantitative), Introduction to other techniques, Applications, Special techniques of imaging, Electron backscattering diffraction.

**MSE 2045 Advanced Ferrous Physical Metallurgy (3 credits)** The first part of the course reviews the basic concepts of the physical metallurgy of plain carbon steels, including the phase diagram and the various phase transformations that can occur. The second part of the course discusses high-strength, low-alloy steels along with their processing and heat treatment. The third part of the course reviews sheet steels for high formability applications. The fourth part of the course discusses specialty steels such as stainless steels and tool steels. Throughout this course, the relationship that exists among composition, processing, microstructure and properties will be emphasized.

**MSE 2046 Physical Metallurgy of Engineering Alloys (3 credits)** Property requirements of engineering alloys are discussed: strength, toughness, formability, weldability, fatigue resistance, corrosion/oxidation resistance. Review is made of pertinent phase diagrams, transformations and microstructures in the Fe-Fe<sub>3</sub>C and other alloy systems. Composition, processing, microstructure and properties of important structural steels, sheet steels, stainless steels, tool steels, aluminum alloys, titanium alloys, as well as nickel-based and copper-based alloys will be presented. Case studies, design problems and selection criteria are discussed.

**MSE 2047 Analysis and Characterization at the Nano-Scale (3 credits)** This course offers a survey of micro-analytical, microscopy and diffraction methods that

are widely used for the analysis of composition, chemistry, structure, scale and morphology of advanced materials. It introduces the most basic concepts required to understand experimental data obtained with these modern techniques. The main objectives of the course are to enable students to interpret and evaluate relevant data sets presented in the research literature and to identify experimental tools to solve a given nano-research characterization problem. Some prerequisite basic knowledge of the structure of solid matter (E.G. crystals and amorphous materials), diffraction methods (E.G. x-ray diffraction) and processing-property-structure relationships in materials is expected.

**MSE 2050 Gas-Metal Reactions (3 credits)** This course will cover the fundamental and applied aspects of gas-metal reactions, particularly with regard to high temperature oxidation and corrosion. The basic aspects of thermodynamics of gas-solid reactions and diffusion in alloys and inorganic compounds will be reviewed. The growth of reaction product layers on pure metals will be described followed by an extensive treatment of alloy oxidation with particular emphasis on the development of protective layers by "selective oxidation". The principles will be illustrated using various technologically important systems including ferrous alloys, Ni-base superalloys, intermetallic compounds, and refractory metals. The following special topics will then be discussed: stresses in oxide films and film adhesion, mixed oxidant corrosion, hot corrosion, corrosion of ceramics, and the use of metallic coatings and thermal barrier coatings for the protection of high-temperature components.

**MSE 2055 Principles of Solidification Engineering (3 credits)** Study of fundamental phenomenon during the formation of crystalline materials. Delineation of the processing parameters that control crystal perfection, solidification substructure, grain size and shape, microsegregation, macrosegregation, microporosity, inclusions, mechanical properties, and physical properties. Application of fundamental principles to the processing of single crystals, ingots, castings, and composites.

**MSE 2067 Elements of Materials Science and Engineering 1 (3 credits)** Course is primarily designed for graduate students entering the program without a degree in a field of materials engineering. Bonding and structure of materials; thermodynamics and phase diagrams; imperfections in crystals; and rate processes.

**MSE 2068 Elements of Materials Science and Engineering 2 (3 credits)** Course is primarily designed for graduate students entering the program without a degree in a field of materials. Mechanical properties: plastic deformation, mechanical properties and microstructure control; high-temperature deformation; deformation of amorphous materials. Electromagnetic properties; electrons in solids; electronic transport; junctions; magnetic properties; dielectric and optical properties.

**MSE 2069 Materials Science of Nanostructures (3 credits)** A graduate level course that reviews the theories and phenomena associated with solid structures that lie in the nano- (or meso-) scale regime from 1 to 1000 nm. Engineered

structures of these dimensions have unique properties due to their size, including 1) surface and interface-dominated energy considerations governing shape and phase formation, 2) optical interactions due to confinement effects, 3) unique electronic/quantum effects due to confinement. The course will survey the issues associated with creation, analysis, and theoretical modeling of these structures-with a materials science (kinetics-thermodynamics) perspective. Some topics may vary from semester to semester.

**MSE 2071 Properties of Ceramics (3 credits)** Microstructure of ceramics; principles and application to ceramic products; thermal properties; mechanical properties; elasticity and strength, plastic deformation, and creep.

**MSE 2072 Ceramic Processing (3 credits)** This course concentrates on the processing of ceramics from powders. It follows the stages common to all powder processing of materials including: powder synthesis, powder characterization, powder forming and sintering. In each stage, emphasis will be placed on the underlying physical principles and the ways in which these principles can be used to describe and control the process. New techniques such as sol-gel processing of thin films, fibers and monoliths will also be described. Finally, the basic steps in the processing of glass will be reviewed.

**MSE 2073 MSE Ceramic Materials (3 credits)** This course involves a comprehensive treatment of the structure-property relationships of ceramic materials for students with a background in materials science and engineering. Topics include: crystal structures of ceramics and their effect on physical and chemical properties, the structure and properties of oxide glasses and glass ceramics, defects and transport properties in oxides, ceramic phase diagrams and microstructure-property relationships, sintering and crystallization.

**MSE 2074 Surfaces and Colloids (3 credits)** Concepts from physical chemistry and transport phenomena are extended to study surface and colloidal phenomena, and related applications to materials processing and separations technology. Topics include: molecular theory of surface tension, surface energy surface thermodynamics, adsorption, electrostatic double layer, interparticle forces in aqueous and non-aqueous dispersions, dominant forces on the colloidal and meso-length scale, colloid stability, electrokinetic phenomena, and suspension rheology, surface probes.

**MSE 2077 Thin Film Processes and Characterization (3 credits)** This course will be an overview of the major thin film processing methods and the primary techniques to characterize thin surfaces and interfaces. Topics to be included in the first part of the course include: vacuum science and technology, thin-film deposition techniques, such as physical vapor deposition (PVD), molecular beam epitaxy (MBE), and chemical vapor deposition (CVD), as well as the fundamental surface processes of epitaxial growth. In the second part of the course, the principles and applications of modern structural and analytical techniques will be presented that use electrons, photons, ions, etc. to probe the surface, near surface and interface regions. Some of the techniques that will be covered include electron microscopy (including situ), Auger electron spectroscopy (AES), X-ray photoelectron

spectroscopy (XPS), atomic force microscopy (AFM) and scanning tunneling microscopy (STM).

**MSE 2078 Nanoparticles: Science and Technology (3 credits)** This interdisciplinary course introduces students to the science and technology of nanoparticles. Synthesis of nanoparticles will be discussed. Applications of nanoparticles for advanced electronic, magnetic, biomedical, catalysis and other areas will be presented.

**MSE 2084 INTRODUCTION TO POLYMER SCIENCE (3 credits)** Introduction to basic concepts of polymer science. Kinetics and mechanism of polymerization, synthesis and processing of polymers. Relationship of molecular conformation, structure and morphology to physical and mechanical properties. Structural and physical aspects of polymers. Molecular and atomic basis for polymer properties and behavior. Characteristics of thermoplastic and thermoset polymers for single and multicomponent systems. Understanding of the viscoelastic and relaxation behavior of single and multicomponent systems. Thermodynamics and kinetics of transition phenomena. Structure, morphology and behavior.

**MSE 2094 Special Advanced Seminar (1 to 3 credits)**

**MSE 2110 Nuclear Materials (3 credits)** This course presumes that students have the knowledge base needed to understand materials issues associated with the design and operation of nuclear power plants, such as basic concepts of physical metallurgy, a mechanistic and microstructural-based view of material properties, and basic metallurgical principles. This course will cover the metallurgy and phase diagrams of alloy systems important in the design of commercial nuclear power plants. The micro-structural changes that result from reactor exposure (including radiation damage and defect cluster evolution) are discussed in detail. The aim is to create a linkage between changes in the material microstructure and changes in the macroscopic behavior of the material. Irradiation on corrosion performance, as well as the effects of primary and secondary coolant chemistry on corrosion. Both mathematical methods and experimental techniques are emphasized so that theoretical modeling is guided by experimental data. Materials issues in current commercial nuclear reactors and materials issues in future core and plant designs are covered.

**MSE 2111 Materials for Energy Generation and Storage (3credits)** The objective of this course is to provide an overview of the important renewable energy resources and the modern technologies to harness and store them. After taking MSE 2111, students are expected to develop a solid scientific and technological understanding of new alternative energy technologies. This course will give an overview on harnessing renewable energy resources and storing collected energy. In each topic, issues relevant to basic principle and technological barriers limiting the use of non-fossil energy will be discussed.

**MSE 2112 Nanoscale Modeling and Simulation: Molecular Dynamics (3 credits)** This course teaches the essentials of molecular dynamics (MD) simulations. It covers topics on classical mechanics, quantum mechanics, statistical

mechanics, thermodynamics, and continuum mechanics, and their role in atomistic scale modeling and simulation. Atomic structure, bonding, and defects in materials as well as techniques for modeling them are also discussed.

**MSE 2113 Nanoscale Modeling and Simulation: Density Functional Theory (3 credits)** The course covers both the fundamentals and the applications of density functional theory (DFT) for predicting the electronic structure and material properties of condensed matters. Topics include electronic structure of atoms and crystals, atomic pseudopotentials, plane wave based DFT method, localized orbital DFT method, augmented function DFT method, and various applications related to determining properties of nanomaterials. Students gain hands-on experience using state-of-the-art DFT computation software.

**MSE 2115 Heat Transfer and Fluid Flow in Nuclear Plants (3 credits)** This course provides advanced knowledge to promote understanding and application of thermal and hydraulic tools and procedures used in reactor plant design and analysis. It assumes that the student has a fundamental knowledge base in fluid mechanics, thermodynamics, heat transfer and reactor thermal analysis. The focus of the course is on physical and mathematical concepts useful for design and analysis of light water nuclear reactor plants. Applications of mass, momentum, and energy balances are combined with use of water properties to analyze the entire reactor plant complex as a whole. Principles are applied through the application of major industry codes to specific cases.

**MSE 2130 Environmental Issues and Solutions for Nuclear Power (3 credits)** This course will be developed in conjunction with University of Pittsburgh faculty with an interest in environmental issues impacting the nuclear power industry including school of engineering faculty involved with the Mascaro sustainability initiative, faculty involved from the department of civil and environmental engineering and faculty from the graduate school of public and international affairs. The course will address such topics as sustainable energy resources, engineering and societal ethical concerns, risk analysis and future energy supplies general and as each of these topics relates to such specific issues as the nuclear fuel cycle, nuclear reactor safety, nuclear waste disposal and transportation, and Gen IV and the hydrogen economy. Students will better understand the socio-economic issues surrounding achieving a sustainable nuclear power future as it impacts fuel acquisition plant operation and waste disposal.

**MSE 2997 MS Research (1 to 12 credits)**

**MSE 2998 Graduate Projects (1 to 3 credits)**

**MSE 2999 MS Thesis (1 to 12 credits)**

**MSE 3001 Practicum (1 to 12 credits)** Provide in curriculum practical training in an area related to advanced materials related research.

**MSE 3023 Graduate Seminar (1 credit)** Speakers from academia and industry review their current research on broad areas of interest with materials engineers.

**MSE 3024 Graduate Seminar (1 credit)** Speakers from academia and industry review their current research on broad areas of interest with materials engineers.

**MSE 3997 PhD Research (1 to 12 credits)**

**MSE 3998 Independent Study (1 to 3 credits)**

**MSE 3999 PhD Dissertation (1 to 12 credits)**