

Department of Materials Science and Engineering Courses

Note on Course Numbers

Each Carnegie Mellon course number begins with a two-digit prefix which designates the department offering the course (76-xxx courses are offered by the Department of English, etc.). Although each department maintains its own course numbering practices, typically the first digit after the prefix indicates the class level: xx-1xx courses are freshmen-level, xx-2xx courses are sophomore level, etc. xx-6xx courses may be either undergraduate senior-level or graduate-level, depending on the department. xx-7xx courses and higher are graduate-level. Please consult the Schedule of Classes (<https://enr-apps.as.cmu.edu/open/SOC/SOCServlet>) each semester for course offerings and for any necessary pre-requisites or co-requisites.

27-052 Introduction to NanoScience and Technology

Summer: 9 units

This course is offered within Carnegie Mellon's Advanced Placement Early Admissions (APEA) program. The course is primarily intended to provide an introduction to nanoscience and technology to a wide audience of students at the advanced high school to incoming freshmen level. The course goals are twofold: (1) to provide students with a holistic view of the objectives, opportunities and challenges of the emerging field of nanotechnology and (2) to sensitize students at an early stage of their career to the relevance of the connections among the traditional disciplines as a vital element to the progress in interdisciplinary areas such as nanotechnology. The course will cover: Introduction and fundamental science; Preparation of nanostructures; Characterization of nanostructures; Application examples, Social and ethical aspects of nanotechnology. Admission according to APEA guidelines.

27-100 Engineering the Materials of the Future

Fall and Spring: 12 units

Materials form the foundation for all engineering applications. Advances in materials and their processing are driving all technologies, including the broad areas of nano-, bio-, energy, and electronic (information) technology. Performance requirements for future applications require that engineers continue to design both new structures and new processing methods in order to engineer materials having improved properties. Applications such as optical communication, tissue and bone replacement, fuel cells, and information storage, to name a few, exemplify areas where new materials are required to realize many of the envisioned future technologies. This course provides an introduction to how science and engineering can be exploited to design materials for many applications. The principles behind the design and exploitation of metals, ceramics, polymers, and composites are presented using examples from everyday life, as well as from existing, new, and future technologies. A series of laboratory experiments are used as a hands-on approach to illustrating modern practices used in the processing and characterization of materials and for understanding and improving materials' properties.

27-201 Structure of Materials

Fall: 9 units

This course covers the fundamentals of crystallography and diffraction. Topics covered include: the periodic table of the elements, bonding in different classes of materials, Bravais lattices, unit cells, directions and planes, crystal geometry computations, direct and reciprocal space, symmetry operations, point and space groups, nature of x-rays, scattering in periodic solids, Bragg's law, the structure factor, and the interpretation of experimental diffraction patterns. 24 crystal structure types of importance to various branches of materials science and engineering will be introduced. Amorphous materials, composites and polymers are also introduced. This course includes both lectures and laboratory exercises.

Prerequisite: 21-122 Min. grade C

27-202 Defects in Materials

Fall: 9 units

Defects have a fundamental influence on the properties of materials, including deformation, electrical, magnetic, optical, and chemical properties, as well as the rates of diffusion in solids. As such, by the controlling the population of intrinsic and extrinsic defects, one can tailor the properties of materials towards specific engineering applications. The objective of this course, which includes classroom and laboratory sessions, is to define approaches to quantifying the populations and properties of defects in crystals. The course will be divided into three sections: point defects, dislocations, and planar defects. The formation of point defects and their influence on diffusion, electrical, and magnetic properties will be considered. The properties and characteristics of dislocations and dislocation reactions will be presented, with a focus on the role of dislocations in deformation. The crystallography and energetics of planar defects and interfaces will also be described, with a focus on microstructural evolution at high temperatures. Time permitting, volume defects or other special topics are also discussed.

Prerequisites: 27-201 or 27-215 or 21-122 Min. grade C or 21-120 Min. grade C

27-205 Introduction to Materials Characterization

Spring: 3 units

The course introduces the modern methods of materials characterization, including characterization of microstructure and microchemistry of materials. A classroom component of the course will introduce the wide array of methods and applications of characterization techniques. Basic theory will be introduced where needed. Students will then be instructed in the use of several instruments such as AFM, SEM, and EDS, using a hands-on approach. All instruments are part of the existing lab facilities within MSE and CIT. The methods learned in this course will serve the student during several other higher level courses, such as the Senior level MSE Capstone Course (27-401).

27-210 Materials Engineering Essentials

Fall: 6 units

This course approaches professional skill holistically, having materials science and engineering students understand that being a professional includes having competencies and responsibilities that are personal, organizational and professional.

Prerequisites: 21-120 Min. grade C or 21-122 Min. grade C

27-211 Structure of Materials (Minor Option)

6 units

This course is identical to 27-201, but without the 3-unit lab component.

27-212 Defects in Materials (Minor Option)

6 units

THIS IS FOR THE MSE MINOR ONLY: Defects have a fundamental influence on the properties of materials, including deformation, electrical, magnetic, optical, and chemical properties, as well as the rates of diffusion in solids. As such, by the controlling the population of intrinsic and extrinsic defects, one can tailor the properties of materials towards specific engineering applications. The objective of this course, which includes classroom and laboratory sessions, is to define approaches to quantifying the populations and properties of defects in crystals. The course will be divided into three sections: point defects, dislocations, and planar defects. The formation of point defects and their influence on diffusion, electrical, and magnetic properties will be considered. The properties and characteristics of dislocations and dislocation reactions will be presented, with a focus on the role of dislocations in deformation. The crystallography and energetics of planar defects and interfaces will also be described, with a focus on microstructural evolution at high temperatures. Time permitting, volume defects or other special topics are also discussed.

27-215 Thermodynamics of Materials

Fall: 12 units

The first half of the course will focus on the laws of thermodynamics and the inter-relations between heat, work and energy. The concept of an equilibrium state of a system will be introduced and conditions which must be satisfied for a system to be at equilibrium will be established and discussed and the concepts of activity and chemical potential introduced. The second half of the course will focus on chemical reactions, liquid and solid solutions, and relationships between the thermodynamics of solutions and binary phase diagrams.

27-216 Transport in Materials

Spring: 9 units

This course is designed to allow the student to become familiar with the fundamental principles of heat flow, fluid flow, mass transport and reaction kinetics. In addition, the student will develop the skills and methodologies necessary to apply these principles to problems related to materials manufacture and processing. Topics will include thermal conductivity, convection, heat transfer equations, an introduction to fluid phenomena viscosity, etc., Newtons and Stokes Laws, mass momentum balances in fluids, boundary layer theory, diffusion and absolute reaction rate theory. Where appropriate, examples will be taken from problems related to the design of components and the processing of materials.

Prerequisites: 27-215 and 15-110

27-217 Phase Relations and Diagrams

Spring: 12 units

Stability of structures. Hume-Rothery rules. Free energy-composition curves with applications to binary and ternary phase diagrams. Quantitative concepts of nucleation and growth with examples from solidification. Development of microstructures in various classes of phase diagram under near-equilibrium conditions. Atomic mechanisms of solid state diffusion and approach to equilibrium through diffusion.

Prerequisites: 27-201 and 27-215

27-299 Professional Development I

Fall: 1 unit

This is a course that is designed to teach engineering business and professional skills to the MSE students. It is attended by sophomores, juniors and seniors and the courses Professional Topics I, II and III are given once per year on a three year cycle. Year 1: Work Place Skills, Leadership Skills and Teams Year 2: Project Management Year 3: Ethics, Business Planning, Lifetime Learning Although the course is not specifically designed as "metals, polymers, ceramics and composites", real world problems are used for examples and discussions. Assignments, when used, (for example, in project management or business planning) can be case studies or typical assignments a materials scientist may encounter during his/her employment.

27-301 Microstructure and Properties I

Fall: 9 units

The objective of this courses and its companion 27-302 is to convey some of the essential concepts in materials science and engineering that relate material properties (strength, magnetism, thermal expansion) to microstructure (crystal structure, dislocations structure, grain structure, precipitate structure, composite structure) in single phase materials. The relationships will be illustrated with examples of both idealized and technological materials. The course will draw upon many aspects of materials science such as defects, phase transformations etc. The course includes both lectures and laboratory exercises.

Prerequisites: 27-216 and 27-217

27-311 Polymeric Biomaterials

Spring: 9 units

This course will provide students with an introduction to polymers used in medical applications. Following a brief discussion of the physical properties of polymers and tissues, we will survey important classes of polymeric biomaterials, discussing material preparation, processing, properties and applications. Topics will include silicone elastomers, degradable hydrogels, ultra-high molecular weight polyethylene, polyurethanes, polyesters, and biopolymers such as silks and collagen. In addition, students will participate in a semester-long entrepreneurship project where they propose a new medical technology based on polymeric biomaterials. This semester we will discuss this primarily in the context of materials for wound healing applications. Student teams will perform market research on wound healing products, propose a novel bioactive dressing for wound healing applications, and identify methods for the testing and production of their product.

27-323 Powder Processing of Materials

Fall: 9 units

This course addresses the methods used in, and the principles that underlie, powder processing of metals and ceramics. Aspects of powder processing will be discussed in relation to the use of materials in engineering applications. The relationship between processing methods and materials performance in select applications will be discussed using specific materials examples including metals and ceramics. The course is broken down into three main parts: (1) understanding, selecting, and controlling powder characteristics; (2) powder handling, compaction, and forming techniques; and (3) drying, burnout, densification, sintering, and grain growth in powder compacts. Topics include chemical thermodynamics, reaction kinetics, surfaces, colloids, dispersions, process engineering, powder handling, powder compaction, shape forming, and densification, and sintering.

Prerequisites: 27-215 and 27-216 and 27-202 and 27-100

27-324 Introduction to Polymer Science and Engineering

Fall: 9 units

This course introduces the fundamental properties of polymer materials and the principles underlying the design as well as the engineering and manufacturing of polymer materials. The basic characteristics of macromolecules will be discussed followed by an introduction to relevant forming technologies and their significance to material performance. Technologically relevant engineering properties of polymer materials will be introduced with focus on mechanical, electrical, and optical properties. Selected case studies and design projects will introduce students to the various stages of technical product development, i.e. problem analysis, material selection and processing plan. (

27-357 Introduction to Materials Selection

Spring: 6 units

The objective of this course is to teach the fundamentals of materials science as related to metals and metal alloys. The topics to be covered include crystal structure, defects, diffusion, binary phase diagrams, microstructure and processing, elastic and plastic deformation, equations of elasticity for isotropic materials, deformation of single crystal, slip systems, the tensile test, Von Mises yield criteria, strengthening mechanisms, phase transformations in steels, microstructures of steels, fracture and toughness, creep and corrosion.

27-367 Selection and Performance of Materials

Spring: 6 units

This course teaches the selection methodologies for materials and processes for satisfaction of a design goal. Topics such as performance under load, shape effects, material properties (intrinsic and as influenced by processing) are discussed and applied so as to determine the fitness of use of materials for applications. Expanded topics include economics, codes and standards, environmental and safety regulations, professional ethics and life cycle analysis where applicable. The course incorporates a project where virtual teams work to provide material selection for a specific application problem. Prerequisites: 27-100

Prerequisites: 27-100 and 27-301

27-399 Professional Development II

Fall: 1 unit

This is a course that is designed to teach engineering business and professional skills to the MSE students. It is attended by sophomores, juniors and seniors and the courses Professional Topics I, II and III are given once per year on a three year cycle. Year 1: Work Place Skills, Leadership Skills and Teams Year 2: Project Management Year 3: Ethics, Business Planning, Lifetime Learning Although the course is not specifically designed as "metals, polymers, ceramics and composites", real world problems are used for examples and discussions. Assignments, when used, (for example, in project management or business planning) can be case studies or typical assignments a materials scientist may encounter during his/her employment.

27-401 MSE Capstone Course I

Fall: 6 units

This is the first of 2 course that together fulfill the Capstone requirement. This capstone course introduces the student to the methodology used for projects and team based research as practiced in the Materials Science and Engineering workplace. This is a project course that requires the knowledge relationship among processing, structure, and performance to address an important contemporary problem in materials science and engineering. Student taking this course will work in a team environment to complete a design project to resolve scientific and engineering issues relating to materials. Research topics will be selected from a list of material problems or research concepts generated from companies or academia - industry research partnerships. This course will establish the research goals, review applicable research methodologies, introduce project management skills and discuss ethical concepts as teams assemble and set their research directions. On the topic selected, the work product is a report that provides clear definition of the problem being addressed, sets out a methodology for the research, includes a literature review, and reports early experimentation results and provides recommendations for future work.

Prerequisites: 27-367 and 27-205 and 27-301

27-402 MSE Capstone Course II

Spring: 6 units

This is the second of 2 courses that together fulfill the Capstone requirement. This capstone course introduces the student to the methodology used for projects and team based research as practiced in the Materials Science and Engineering workplace. This is a project course that requires the knowledge relationship among processing, structure, and performance to address an important contemporary problem in materials science and engineering. Student taking this course will work in a team environment to complete a design project to resolve scientific and engineering issues relating to materials. The team based research project is continued from 27-401. In this course, team participation and communication are important topics as the students conclude their research projects and prepare for final presentation and project closure. The presentation and reports are to be technical and professional in structure, and show outcomes that are relatable to the proposed project goal(s) while meeting applicable realistic constraints such as economic, environmental, social, political, ethical, health and safety, manufacturability, and sustainability.

Prerequisite: 27-401

27-410 Computational Techniques in Engineering

Spring: 12 units

This course covers mathematical methods that allow formulation of engineering and science problems in a manner that makes them computationally tractable for numerical solutions. Numerical approaches to solving engineering or science problems allow one to perform computer simulations that can answer key questions without actual experimental effort (which can often be costly and time-consuming). The course is divided into two major modules. The first module develops foundational background in modeling, computers, error analysis, linear algebra, and curve fitting. The second module builds on the first to develop skills in numerical differentiation and integration, and continues with techniques for computational solution of ordinary and partial differential equations. Students will learn how to set up engineering or science problems in a manner that allows numerical solutions to be obtained by either writing simple computer programs or macros that interface with commercially available software packages such as MATLAB or Mathematica. The course is also cross-listed as 18-411

27-411 Engineering Biomaterials

Fall: 9 units

This course will cover structure-processing-property relationships in biomaterials for use in medicine. This course will focus on a variety of materials including natural biopolymers, synthetic polymers, and soft materials with additional treatment of metals and ceramics. Topics include considerations in molecular design of biomaterials, understanding cellular aspects of tissue-biomaterials interactions, and the application of bulk and surface properties in the design of medical devices. This course will discuss practical applications of these materials in drug delivery, tissue engineering, biosensors, and other biomedical technologies. Must be a Junior or Senior in CIT or obtain permission of instructor.

27-421 Processing Design

Fall: 6 units

In this course, the concepts of materials and process design are developed, integrating the relevant fundamental phenomena in a case study of a process design. The course includes basic science and engineering as well as economic and environmental considerations. The case study is on environmentally acceptable sustainable steelmaking. Other case studies in materials processing could be used.

27-432 Electronic and Thermal Properties of Metals, Semiconductors and Related Devices

Intermittent: 9 units

Fall even years This is Part I of a two-part course (Part II is 27-433) sequence concerned with the electrical, dielectric, magnetic and superconducting properties of materials. Students taking Part I will develop an in-depth understanding, based on the modern theories of solids, of the electrical, electronic and thermal properties of metals and semiconductors and the principles of operation of selected products and devices made from these materials. Overarching and interrelated topics will include elementary quantum and statistical mechanics, relationships between chemical bonds and energy bands in metals and semiconductors, the roles of phonons and electrons in the thermal conductivity of solids, diffusion and drift of electrons and holes, the important role of junctions in the establishment and control of electronic properties of selected metal- and semiconductor-based devices. Examples of commercial products will be introduced to demonstrate the application of the information presented in the text and reference books and class presentations. Additional topics will include microelectro-mechanical systems and nanoelectronics.

27-433 Dielectric, Magnetic, Superconducting Properties of Materials & Related Devices

Intermittent: 9 units

Fall odd years: 9 units This is Part II of a two-part course sequence (Part I is 27-432) concerned with the electrical, dielectric, magnetic and superconducting properties of materials. Students taking Part II will develop an in-depth understanding, based on the modern theories of solids, of the dielectric, magnetic and superconducting properties of materials and the principles of operation of selected products and devices made from these materials. Topics will include relationships between chemical bonds and energy bands in dielectric and magnetic materials; polarization mechanisms in materials and their relationship to capacitance, piezoelectricity, ferroelectricity, and pyroelectricity; magnetization and its classification among materials; magnetic domains; soft and hard magnets; and the origin, theory and application of superconductivity. Examples of commercial products will be introduced to demonstrate the application of the information presented in the text and reference books and class presentations.

27-445 Structure, Properties and Performance Relationships in Magnetic Materials

Spring: 9 units

This course introduces the student to intrinsic properties of magnetic materials including magnetic dipole moments, magnetization, exchange coupling, magnetic anisotropy and magnetostriction. This is followed by discussion of extrinsic properties including magnetic hysteresis, frequency dependent magnetic response and magnetic losses. This will serve as the basis for discussing phase relations and structure/properties relationships in various transition metal magnetic materials classes including iron, cobalt and nickel elemental magnets, iron-silicon, iron-nickel, iron-cobalt and iron platinum. This will be followed by a discussion of rare earth permanent magnets, magnetic oxides, amorphous and nanocomposite magnets. Polymers used in Electromagnetic Interference (EMI) Absorbers applications will also be covered.

27-454 Supervised Reading

Spring

This course provides the opportunity for a detailed study of the literature on some subject under the guidance of a faculty member, usually but not necessarily in preparation for the Capstone Course, 27-401/402.

27-499 Professional Development III

Fall: 1 unit

This is a course that is designed to teach engineering business and professional skills to the MSE students. It is attended by sophomores, juniors and seniors and the courses Professional Topics I, II and III are given once per year on a three year cycle. Year 1: Work Place Skills, Leadership Skills and Teams Year 2: Project Management Year 3: Ethics, Business Planning, Lifetime Learning Although the course is not specifically designed as "metals, polymers, ceramics and composites", real world problems are used for examples and discussions. Assignments, when used, (for example, in project management or business planning) can be case studies or typical assignments a materials scientist may encounter during his/her employment.

27-501 Invention & Innovation for Materials Intensive Technologies Part 1

Fall: 4.5 units

Two 4.5 unit classes that can be taken in sequence or as stand-alone mini's. Courses will be cross-listed between EPP and MSE. This course is intended to instill a sense of how technologies are conceived and brought to market. The students will be exposed to a variety of formalized invention and innovation processes/concepts and will be asked to complete projects that will pull from the full range of their engineering training. It is intended for seniors who are eager to creatively apply their learned knowledge skills, and who are interested in invention, innovation, and entrepreneurship. The first half (part 1 (27-501), mini 1) will focus on the process of invention for devices and technologies that are enabled by materials functionality. This will start by providing historical context and addressing the questions "What is invention?" This will be followed by an assessment of various systematic methods by which the process of invention is practiced, with a specific focus on materials intensive devices and products. The second half of the course (part 2 (27-502) mini 2) will examine innovation theory in the context of materials intensive technologies. Specifically, the concepts of incumbency, disruption, value chain, supply chain, funding models and paths to market will be addressed. In this class, significant time will be dedicated to covering the impact of international market and technology development.

27-502 Invention and Innovation for Materials Intensive Technologies Part 2

Fall and Spring: 4.5 units

ALL STUDENTS MUST HAVE TAKEN AND SUCCESSFULLY PASSED 27-501 AS A PRE-REQ. Two 4.5 unit classes that can be taken in sequence or as stand-alone mini's. Courses will be cross-listed between EPP and MSE. This course is intended to instill a sense of how technologies are conceived and brought to market. The students will be exposed to a variety of formalized invention and innovation processes/concepts and will be asked to complete projects that will pull from the full range of their engineering training. It is intended for seniors who are eager to creatively apply their learned knowledge skills, and who are interested in invention, innovation, and entrepreneurship. The first half (part 1 (27-501), mini 1) will focus on the process of invention for devices and technologies that are enabled by materials functionality. This will start by providing historical context and addressing the questions "What is invention?" This will be followed by an assessment of various systematic methods by which the process of invention is practiced, with a specific focus on materials intensive devices and products. The second half of the course (part 2 (27-502) mini 2) will examine innovation theory in the context of materials intensive technologies. Specifically, the concepts of incumbency, disruption, value chain, supply chain, funding models and paths to market will be addressed. In this class, significant time will be dedicated to covering the impact of international market and technology development.

27-514 Special Topics

Spring: 9 units

This course will develop the understanding required for materials science and engineering for additive manufacturing. The emphasis will be on powder bed machines for printing metal parts, reflecting the research emphasis at CMU. The full scope of methods in use, however, will also be covered. The topics are intended to enable students to understand which materials are feasible for 3D printing. Accordingly, high power density welding methods such as electron beam and laser welding will be discussed, along with the characteristic defects. Since metal powders are a key input, powder-making methods will be discussed. Components once printed must satisfy various property requirements hence microstructure-property relationships will be discussed because the microstructures that emerge from the inherently high cooling rates differ strongly from conventional materials. Defect structures are important to performance and therefore inspection. Porosity is a particularly important feature of 3D printed metals and its occurrence depends strongly on the input materials and on the processing conditions. The impact of data science on this area offers many possibilities such as the automatic recognition of materials origin and history. Finally the context for the course will be discussed, i.e. the rapidly growing penetration of the technology and its anticipated impact on manufacturing.

27-515 Introduction to computational materials science

Fall: 9 units

This course introduces students to the theory and practice of computational materials science from the electronic to the microstructural scale. Both the underlying physical models and their implementation as computational algorithms will be discussed. Topics will include: Density functional theory Molecular dynamics Monte Carlo methods Phase field models Cellular automata Data science Coursework will utilize both software packages and purpose-built computer codes. Students should be comfortable writing, compiling, and running simple computer programs in C, C++, Fortran, MatLab, Python, or comparable environment.

27-519 Computational Thermodynamics

Spring: 9 units

Computational thermodynamics is a powerful tool of a Materials Engineer. We will examine how thermodynamic simulation software outputs an equilibrium calculation from a list of input conditions. This requires a description of Gibbs energy minimization calculations, Gibbs energy models, and the construction of these models from thermodynamic data. At the end of the class students should be able to use thermodynamic simulation software to solve engineering problems while recognizing its limitations. This class is for upper-level undergraduates and graduate students interested in these computational tools.

27-520 Tissue Engineering

Spring: 12 units

This course will train students in advanced cellular and tissue engineering methods that apply physical, mechanical and chemical manipulation of materials in order to direct cell and tissue function. Students will learn the techniques and equipment of bench research including cell culture, immunofluorescent imaging, soft lithography, variable stiffness substrates, application/measurement of forces and other methods. Students will integrate classroom lectures and lab skills by applying the scientific method to develop a unique project while working in a team environment, keeping a detailed lab notebook and meeting mandated milestones. Emphasis will be placed on developing the written and oral communication skills required of the professional scientist. The class will culminate with a poster presentation session based on class projects. Prereqs: Cell biology and Biomaterials, or permission of instructor.

27-533 Principles of Growth and Processing of Semiconductors

Fall: 6 units

Development of a fundamental understanding of material principles governing the growth and processing of semiconductors. Techniques to grow and characterize bulk crystals and epitaxial layers are considered. The processing of semiconductors into devices and the defects introduced thereby are discussed. The roles of growth- and processing-induced defects in determining long term reliability of devices are examined.

27-542 Processing and Properties of Thin Films

Fall: 9 units

This course is designed to provide an introduction to the science and technology of thin films, with special emphasis on methods to produce thin films and relationships between growth conditions and thin film properties. Topics include (1) various methods of thin film production, such as evaporation, sputtering and chemical vapor deposition, (2) nucleation and growth processes, (3) dimensional, chemical, and structural characterization of thin films and (4) properties and applications, such as conductivity and thin film solar cells.

27-551 Properties of Ceramics and Glasses

Spring: 9 units

This course describes some of diverse properties of ceramics and glasses, with a focus on those relevant to modern engineering applications. It includes discussions of the underlying science of selected ceramic properties, such as thermal properties, including heat capacity and thermal expansion; mechanical properties, including strength, toughness, and environmental effects; electrical properties, including electronic and ionic conductivity; dielectric properties, including piezoelectricity and ferroelectricity; and optical properties, as they pertain to glasses and lasers. Numerous examples of current applications, such as lasers, sensors, fiber optics, multilayer capacitors, solid oxide fuel cells, or thermoelectrics, are discussed throughout the course to illustrate the engineering relevance of fundamental phenomena. This class will be co-taught with 27-751. Undergraduates taking the course will have separate homework and exams from the graduate students, and will be graded separately from the graduate students.

27-555 Materials Project I

Fall

This course is designed to give experience in individualized research under the guidance of a faculty member. The topic is selected by mutual agreement, and will give the student a chance to study the literature, design experiments, interpret the results and present the conclusions orally and in writing.

27-556 Materials Project II

Spring

Second semester of Materials Project. This course is designed to give experience in individualized research under the guidance of a faculty member. The topic is selected by mutual agreement, and will give the student a chance to study the literature, design experiments, interpret the results and present the conclusions orally and in writing.

27-561 Special Topics: Kinetics of Metallurgical Reactions and Processes

Fall: 6 units

This class uses examples from the ironmaking and steelmaking to illustrate different rate-determining reaction steps. Reaction times in ironmaking and steelmaking process vary quite widely; the fundamental origins of the large differences in reaction time are analyzed, after a brief overview of the main reactions and process steps in ironmaking and steelmaking. Particular skills to be practiced and developed include derivation of the mathematical relationships which describe the rates of metallurgical processes which involve heat transfer, and mass transfer for solid-gas, liquid-gas and liquid-liquid reactions; quantifying the expected rates of such reactions; identification of rate-determining steps, based on calculated rates and observed reaction rates; predicting the effects of process parameters such as particle size, stirring, temperature and chemical compositions of phases on the overall rate; and critical evaluation of kinetic data and models in scientific papers on metallurgical reactions.

27-565 Nanostructured Materials

Intermittent: 9 units

Fall even years: This course is an introduction to nanostructured materials or nanomaterials. Nanomaterials are objects with sizes larger than the atomic or molecular length scales but smaller than microstructures with at least one dimension in the range of 1-100 nm. The physical and chemical properties of these materials are often distinctively different from bulk materials. This course introduces the basic thermodynamic concepts related to the phases, chemical activity and synthesis of nanomaterials including metallic, semiconductor, inorganic, liquid crystalline, polymeric and surfactant systems. The characterization of the structure of nanomaterials and their applications are also explored. At the end of the course, students should understand the relationship between the nanoscale structures, properties and performance of nanomaterials.

27-566 Special Topics in MSE: Using Matls Informatics to Assess Societal Impact of Matls

Fall and Spring: 9 units

Using Materials Informatics to Assess Societal Impact of Materials: For years Material Science and Engineering in general has been taught with emphasis on the technology and then looks at how this technology fits in to society through applications. This course will attempt to put forth an innovative approach, combining new data mining techniques, data analysis, and material fundamentals (materials informatics) to see if material failure patterns can be extracted from social media. The course will involve instruction on typical material issue that contribute to failures either geographically or temporarily. Students will also be introduced to informatics techniques related to data mining and large database analysis. The intent is to have a mix of lectures and practical project work. This course is primarily intended to be a course directed to CIT students in order to experience an understanding that engineering work is strongly connected to societal. Students that enroll should have completed their class in statistics.

27-570 Molecular and Micro-scale Polymeric Biomaterials in Medicine

9 units

This course will cover aspects of polymeric biomaterials in medicine from molecular principles to device scale design and fabrication. Topics include the chemistry, characterization, and processing of synthetic polymeric materials; cell-biomaterials interactions including interfacial phenomena, tissue responses, and biodegradation mechanisms; aspects of polymeric micro-systems design and fabrication for applications in medical devices. Recent advances in these topics will also be discussed. Pre-requisite: None. Prerequisites: 09-219 or 09-217

27-582 Phase Transformations in Solids

Intermittent: 9 units

Spring even years: In this course the fundamental aspects of solid state phase transformations are presented. The nucleation (homogeneous and heterogeneous) and growth of diffusional and non-diffusional heterogeneous solid state transformations are discussed from the point of view of crystallography, thermodynamics and kinetics, as are the same aspects of homogeneous transformations. Details of such transformations as precipitation, cellular, atomic ordering, massive, spinodal decomposition, displacive, etc. are discussed with specific examples from the Materials Science literature.

27-588 Polymer Physics and Morphology

Intermittent: 9 units

This course introduces the fundamental concepts necessary to understand and determine the structure and properties of polymers in the solid state. The structure of polymers will be discussed with focus on the amorphous, crystalline and liquid-crystalline state. One aim is to provide a student intuition about the organization of polymer molecules in the solid state based on the polymer's chemical structure. Particular attention will be given to scattering techniques as a tool to determine polymer structures in solution and the solid state. The glass transition in amorphous polymers as well as the morphology and kinetics of crystal formation in semi-crystalline polymers will be discussed in detail. The second part of the course will focus on polymer multicomponent materials. Basic concepts of lattice models will be introduced and applied to predict the phase behavior of polymer blends.

27-591 Mechanical Behavior of Materials

Intermittent: 9 units

Spring odd years: Fundamentals of stress and strain. Linear elastic behavior. Tensile testing and yield criteria. Relationships between stress and strain for the case of plastic deformation. Theoretical strength. Tensile tests of single crystals and the idea of a slip system. Shear stress versus shear strain curves for single crystals and the effects of crystal orientation, temperature, atoms in solid solution and precipitates on the shapes of such curves. Taylor's connection between tensile curves of single crystals and those of polycrystalline samples. Dislocations and plastic deformation. Strengthening mechanisms including solid-solution strengthening, strengthening by precipitates, work hardening and grain size effects on strength. Approaches to quantifying the fracture resistance of materials, including the Griffith approach, the energy release rate approach and the stress intensity factor approach. Crack tip behavior including stresses and strains at crack tips and the plastic zone. Fracture mechanisms including ductile fracture, cleavage fracture and intergranular fracture. The fracture of highly brittle materials. Time permitting fatigue and creep of materials will be discussed.

27-592 Solidification Processing

Intermittent: 9 units

Spring odd years: The goal of this course is to enable the student to solve practical solidification processing problems through the application of solidification theory. The objectives of this course are to: (1) Develop solidification theory so that the student can understand predict solidification structure; (2) Develop a strong understanding of the role of heat transfer in castings; (3) Develop an appreciation for the strengths and weaknesses of a variety of casting processes. The first half of the course will be theoretical, covering nucleation, growth, instability, solidification microstructure: cells, dendrites, eutectic and peritectic structures, solute redistribution, inclusion formation and separation, defects and heat transfer problems. The second part of the course will be process oriented and will include conventional and near net shape casting, investment casting, rapid solidification and spray casting where the emphasis will be on process design to avoid defects.

27-620 Basics and Applications of Power Magnetic Devices

Intermittent: 12 units

This course will provide a sound background in the fundamentals of soft magnetic materials and the physics required for magnetic component level design. Fundamental principles will be applied to practical component level design problems. A final design project will leverage analytical and/or finite element simulations. The course is targeted to masters-level students but will be accessible to advanced undergraduate and PhD level students.

27-675 Masters Report

All Semesters

This course is used to indicate whether a student has satisfied the final report requirement for the Master of Science in Materials Science Degree Program. Students in the program will be registered for the course in their final semester of the program.

27-698 Practical Materials Characterization Laboratory

Intermittent: 6 units

This course is designed to give masters students a practical exposure to materials characterization techniques. Students will learn the theory and background of several laboratory techniques, including Scanning Electron Microscopy (SEM), X-ray Diffraction (XRD), Atomic Force Microscopy (AFM) and thermal analysis techniques such as thermogravimetric analysis (TGA) and differential scanning calorimetry (DSC). The course will consist of lectures, followed by laboratory sessions for practical use of the instrumentation. Lectures will provide the necessary background to understand how different materials characterization techniques work; Lab sessions will inform the student on standard operating procedures for the techniques discussed in the lectures.

27-699 Professional Skills in Materials Science and Engineering

Fall: 6 units

This course is intended for students in the masters program in Materials Science and Engineering. The course will expose students to important issues that materials scientists and engineers face when they enter the workforce. The course focuses on professional skills for materials scientists and engineers, covering communication skills, ethics and responsible conduct of research, and evaluating technical literature. The course will end with discussions on how materials science affects the global economy. Course activities will include in-class exercises and assignments based on case studies.

27-709 Engineering Biomaterials

Fall: 12 units

This course will cover structure-processing-property relationships in biomaterials for use in medicine. This course will focus on a variety of materials including natural biopolymers, synthetic polymers, and soft materials with additional treatment of metals and ceramics. Topics include considerations in molecular design of biomaterials, understanding cellular aspects of tissue-biomaterials interactions, and the application of bulk and surface properties in the design of medical devices. This course will discuss practical applications of these materials in drug delivery, tissue engineering, biosensors, and other biomedical technologies. This course is a project-based option for graduate students that is taught concurrently with 42-411.

27-715 Applied Magnetism and Magnetic Materials

Spring: 12 units

In this course we address the physics of magnetism of solids with emphasis on magnetic material properties and phenomena which are useful in various applications. The content of this course includes the origins of magnetism at the atomic level and the origins of magnetic ordering (ferro-, ferri-, and antiferromagnetism), magnetic anisotropy, magnetic domains, domain wall, spin dynamics, and transport at the crystalline level. The principles of magnetic crystal symmetry are utilized to explore the various domains in ferromagnetic crystals, and tensors are used in the description of such magnetic properties as magnetocrystalline anisotropy, susceptibility and magnetostriction. To a limited extent, the applications of magnetism are discussed in order to motivate the understanding of the physical properties and phenomena.

27-718 Soft Materials

Fall: 12 units

The emphasis in this course will be on the emerging unifying physical principles that explain the macroscopic properties of a wide variety of soft materials, e.g., colloids, liquid crystals, surfactants, polymers, and biological structures. At the end of the course, students should understand the concepts, experimental techniques, and open questions in the field. The course is interdisciplinary, and it is expected that enrollment will cover a wide spectrum of students. Therefore, the essential concepts will be taught as necessary. Prerequisites: Graduate standing or permission of instructor.

27-719 Computational Thermodynamics

Spring: 12 units

Computational thermodynamics is a powerful tool of a Materials Engineer. We will examine how thermodynamic simulation software outputs an equilibrium calculation from a list of input conditions. This requires a description of Gibbs energy minimization calculations, Gibbs energy models, and the construction of these models from thermodynamic data. At the end of the class students should be able to use thermodynamic simulation software to solve engineering problems while recognizing its limitations. This class is for graduate students interested in these computational tools.

27-720 Tissue Engineering

Spring: 12 units

This course will train students in advanced cellular and tissue engineering methods that apply physical, mechanical and chemical manipulation of materials in order to direct cell and tissue function. Students will learn the techniques and equipment of bench research including cell culture, immunofluorescent imaging, soft lithography, variable stiffness substrates, application/measurement of forces and other methods. Students will integrate classroom lectures and lab skills by applying the scientific method to develop a unique project while working in a team environment, keeping a detailed lab notebook and meeting mandated milestones. Emphasis will be placed on developing the written and oral communication skills required of the professional scientist. The class will culminate with a poster presentation session based on class projects. Prereqs: Cell biology and Biomaterials, or permission of instructor.

27-721 Processing Design

Fall: 6 units

In this course, the concepts of materials and process design are developed, integrating the relevant fundamental phenomena in a case study of a process design. The course includes basic science and engineering as well as economic and environmental considerations. The case study is on environmentally acceptable sustainable steelmaking. Other case studies in materials processing could be used.

27-722 Basics and Applications of Power Magnetic Devices

Intermittent: 12 units

This course will provide a sound background in the fundamentals of soft magnetic materials and the physics required for magnetic component design. Fundamental principles will be applied to practical component level design problems. A final design project will leverage analytical and/or finite element simulations. The course is targeted to masters-level students but will be accessible to advanced undergraduate and PhD level students. Primary learning objectives are: 1) Establish a fundamental knowledge base of the relevant materials science and physics principles that dictate performance of soft magnetic materials. 2) Establish a strong foundation in the fundamentals of applied electromagnetics required for intelligent application of finite element simulations and other analytical models for magnetic component design. 3) Provide students with experience in performing magnetic component design including material selection and component optimization through assigned problems and a final project.

27-724 Materials for Energy Storage

Intermittent: 6 units

This course will examine functional materials used to store and release electrical energy. An overview of the thermodynamics of power, energy and energy storage will be used to motivate subsequent investigations into the dominant methods in use today: electrochemical, electrical, and electromechanical (chemical/combustion and nuclear processes will not be covered). For each sub-topic, the physical and chemical mechanisms exploited will be discussed, followed by a detailed exposition of specific materials functionality and device applications. Particular focus will be given to several relevant emerging technologies: Li-ion batteries, hydrogen-based fuel cells (polymer proton exchange membrane and solid-oxide based systems), and large capacitors (both electrolytic and dielectric).

27-725 Materials for Nuclear Energy Systems

Spring: 6 units

Students in this course will learn about Materials that are used in nuclear energy systems. The course will cover the full range of materials that are relevant to nuclear energy with a focus on materials subject to irradiation (glasses, steels, nickel alloys, and zirconium alloys). Applications of materials will include waste storage, reactor vessels, turbines, pumps, piping, and fuel elements. For the materials used in each application, the selection and performance criteria will be considered as well as the underlying structure, thermodynamic, and kinetic processes that influence materials properties. The effects of irradiation on materials properties and performance will be examined. Key properties include strength, fracture toughness and corrosion resistance. Many of these properties continue to change over the long service periods expected of components. In addition to lectures and homeworks, each student will complete a detailed case study in which they examine a particular material and application.

27-727 Mechanical Behavior in Extreme Environments

Spring: 6 units

The purpose of this course is to discuss the mechanical behavior of materials used in extreme environments in the production and distribution of energy. The focus will be on the production and refining of oil, conventional power plants and nuclear power plants. The course will begin with a discussion of the materials used in these applications and this discussion will focus on compositions, heat treatment, microstructure and nominal mechanical properties after heat treatment. The materials will include low alloy steels, stainless steels, nickel base alloys and zirconium alloys used as fuel cladding in nuclear reactors. The mechanical behavior discussed will be the behavior of materials at high temperatures, various types of stress corrosion cracking and the toughness of steels used at low temperatures. In addition, various forms of embrittlement associated with long service times at elevated temperatures will be discussed. These will include hydrogen attack, temper embrittlement due to segregation of impurities and alloying elements, the formation of phases which result in embrittlement and embrittlement due to irradiation in nuclear reactors. Many of these materials are expected to be in service for many years so, where time permits, methodologies used to predict mechanical properties after long times in service will be discussed.

27-729 Solid State Devices for Energy Conversion

Intermittent: 6 units

Intensive research efforts have yielded promising new materials approaches to 'alternative' energy conversion technologies, such as solar cells or photovoltaics; thermoelectric materials, which convert waste heat to electricity; metal/semiconductor superlattices for thermionic energy conversion; and fuel cells. At the same time, notable advances have been made in devices that substantially enhance our energy efficiency: e.g., chemical sensors and light-emitting diodes for solid-state lighting. In all of these devices, interfaces between dissimilar materials often govern and/or limit the behavior. In addition to the basic structures and operating principles, this course will cover practical materials interface issues, such as electrical transport, thermal stability, contact resistance, and bandgap engineering, that significantly affect the performance of a variety of energy conversion and energy-saving devices.

27-731 SPECIAL TOPICS: Hard and Superhard Materials

Intermittent: 6 units

This course will focus on the fundamental principles hard and superhard materials and coatings. We will first discuss the origin of hardness across materials, and then describe important examples of materials prized for either their intrinsic or extrinsic hardness. We will focus on the preparation, microstructure, and properties of materials such as diamond, cubic boron nitride and compound carbides. Additionally, we will emphasize the design of novel nano-structured and nano-composite materials and coatings, which are at the frontier of materials science. Finally, the course will present examples of the architecture and processing methods used to generate hard materials and coatings in manufacturing, automotive and aerospace industries.

27-740 Practical Methods in Electron Microscopy

Spring: 6 units

This course is designed to provide instrument training on a transmission electron microscope in the Materials Characterization Facility (MCF) housed in Roberts Engineering Hall. Emphasis will be placed on acquiring the basic skills needed to successfully operate this microscope; this will be achieved by a combination of lectures and hands-on lab sessions. Lectures will provide the necessary background to understand electron scattering techniques, including electron diffraction, bright field and dark field imaging, phase contrast imaging, and energy dispersive x-ray spectroscopy. Lab sessions will inform the student on standard operating procedures for the techniques discussed in the lecture portion of the course. At the end of the course, the student is expected to demonstrate the ability to independently use the transmission electron microscope for basic operations; successful demonstration of such skills will lead to certification for day-use of the JEOL 2000EX transmission electron microscope in the MCF

27-752 Foundations of Semiconductor Nanostructures

Spring: 12 units

This course is designed to provide students with a foundation of the physics required to understand nanometer-scale structures and to expose them to different aspects of on-going research in nanoscience and nanotechnology. Illustrative examples will be drawn from the area of semiconductor nanostructures, including their applications in novel and next-generation electronic, photonic, and sensing devices. The course begins with a review of basic concepts in quantum physics (wave-particle duality, Schrödinger's equation, particle-in-a-box, approximation methods in quantum mechanics, etc.) and then continues with a discussion of bulk three-dimensional solids (band structure, density of states, the single-electron effective-mass approximation). Size effects due to nanometer-scale spatial localization are then discussed within a quantum-confinement model in one-, two-, and three- dimensions for electrons. An analogous discussion for photons is also presented. The basic electronic, optical, and mechanical properties of the low-dimensional nanostructures are then discussed. A select number of applications in electronics, photonics, biology, chemistry, and bio-engineering will be discussed to illustrate the range of utility of nanostructures. Upon completion of the course, students will have an appreciation and an understanding of some of the fundamental concepts in nanoscience and nanotechnology. The course is suitable for first-year graduate students in engineering and science (but advanced undergraduates with appropriate backgrounds may also take it with permission from the instructor). Pre-requisites include 09-511, 09-701, 09-702, 18-311, 27-770, 33-225, 33-234 or familiarity with the material or basic concepts covered in these courses.

27-756 Masters Project

All Semesters

Individual research project, including laboratory, theoretical, library or design work followed by a written or oral report on the work accomplished.

27-759 Molecular Engineering

Spring: 12 units

Unprecedented control over molecular architecture has led to next-generation materials for a broad range of applications. The goal will be to provide students with an understanding of how to design and synthesize organic materials for specific technologies using an approach that integrates content from fundamental polymer science in the context of engineering. Emphasis will be placed on understanding composition-structure-function relationships and how molecular parameters and processing strategies can be tuned to optimize performance. The course will utilize a combination of textbook material as well as articles from the recent scientific and patent literature. Feedstocks, materials, processes, and products will be viewed through life cycle assessments with an emphasis on sustainability. Learning Objectives: At the end of this course students will: (1) gain experience in applying their knowledge of polymer chemistry in preparing materials via radical and condensation reactions in technological applications; (2) learn engineering paradigms related to surface tension, adsorption, film formation, viscoelastic properties of complex fluids, thermodynamics, transport phenomena, and electronic materials used to design advanced materials systems; (3) gain hands-on experience in the preparation, characterization, and testing of advanced materials.

27-761 Special Topics: Kinetics of Metallurgical Reactions and Processes

Fall: 6 units

This class uses examples from the ironmaking and steelmaking to illustrate different rate-determining reaction steps. Reaction times in ironmaking and steelmaking process vary quite widely; the fundamental origins of the large differences in reaction time are analyzed, after a brief overview of the main reactions and process steps in ironmaking and steelmaking. Particular skills to be practiced and developed include derivation of the mathematical relationships which describe the rates of metallurgical processes which involve heat transfer, and mass transfer for solid-gas, liquid-gas and liquid-liquid reactions; quantifying the expected rates of such reactions; identification of rate-determining steps, based on calculated rates and observed reaction rates; predicting the effects of process parameters such as particle size, stirring, temperature and chemical compositions of phases on the overall rate; and critical evaluation of kinetic data and models in scientific papers on metallurgical reactions.

27-763 Foundations of Electron Microscopy

Fall: 12 units

This course provides an in-depth overview of both scanning and transmission electron microscopy methods used in materials research for the characterization of microstructure and crystallography. The course begins with basic quantum mechanics at the level needed to describe electron scattering phenomena in solids, and introduces the basic Schrodinger equation along with several numerical procedures for its solution. Topics covered will at a minimum include: atomic scattering and form factors, dynamical electron scattering, conventional and convergent beam electron diffraction, defect contrast imaging, electron back-scatter diffraction, electron channeling and channeling contrast imaging, Monte Carlo simulations of electron trajectories, inelastic scattering, and an introduction to 3D characterization techniques, including serial sectioning and tomography. Throughout the course, the emphasis will be on the underlying models; students will be expected to participate in practical simulation sessions.

Prerequisite: 27-740

Course Website: <http://www.cmu.edu/blackboard>**27-766 Diffusion in Materials**

Fall: 6 units

This course is designed to allow the student to become familiar with the fundamental principles diffusion in solid materials. The course will include the treatment of diffusion from an atomic scale to micro-structural scales in metals, ceramics, glasses and polymers. In addition, the student will develop skills and methodologies necessary to apply mathematical methods to solve differential equations of relevance to diffusion problems including separation of variables, Laplace transforms and Green's functions. An introduction will be given to the application of numerical solutions. Where appropriate, examples will be taken from problems related to the design of components and the processing and performance of materials.

27-782 Phase Transformations in Solids I

Spring: 12 units

Special topics in applied thermodynamics, with particular emphasis on free energy-composition diagrams and their applications, are developed in some detail. The kinetic equations of both classical and non-classical nucleation theory are then derived. Special emphasis is placed upon the influence of the critical nucleus shape, and the nucleation site, upon nucleation kinetics. The limited experimental evidence available for testing nucleation theory is critically examined. The principal relationships for diffusional growth are next deduced. The structure of interphase boundaries is considered both theoretically and experimentally and its influence upon growth kinetics is demonstrated through comparisons of calculated and measured growth kinetics in model alloy systems. 4 hrs. lec.

27-788 Defects in Materials

Fall: 6 units

This course addresses the fundamental properties of defects in crystalline solids, as well as their effects on properties and behavior of materials. Primary attention is devoted to point and line defects. Somewhat less comprehensive coverage is given to extended defects, including grain boundaries, interphase boundaries and surfaces. 4 hrs. lec.

27-791 Mechanical Behavior of Materials

Spring: 12 units

The intent of the course is to introduce various measures indicative of the performance of materials in applications. Properties often used in selecting materials will be introduced, and connections between these properties and microstructure will be developed. Mechanical properties are emphasized in this course. 4 hrs. lec.

27-792 Solidification Processing

Spring: 12 units

The goal of this course is to enable the student to solve practical solidification processing problems through the application of solidification theory. The objectives of this course are to: (1) Develop solidification theory so that the student can understand predict solidification structure; (2) Develop a strong understanding of the role of heat transfer in castings; (3) Develop an appreciation for the strengths and weaknesses of a variety of casting processes. The first half of the course will be theoretical, covering nucleation, growth, instability, solidification microstructure: cells, dendrites, eutectic and peritectic structures, solute redistribution, inclusion formation and separation, defects and heat transfer problems. The second part of the course will be process oriented and will include conventional and near net shape casting, investment casting, rapid solidification and spray casting where the emphasis will be on process design to avoid defects.

27-795 TBA

Intermittent: 12 units

This course will develop the understanding required for materials science and engineering for additive manufacturing. The emphasis will be on powder bed machines for printing metal parts, reflecting the research emphasis at CMU. The full scope of methods in use, however, will also be covered. The topics are intended to enable students to understand which materials are feasible for 3D printing. Accordingly, high power density welding methods such as electron beam and laser welding will be discussed, along with the characteristic defects. Since metal powders are a key input, powder-making methods will be discussed. Components once printed must satisfy various property requirements hence microstructure-property relationships will be discussed because the microstructures that emerge from the inherently high cooling rates differ strongly from conventional materials. Defect structures are important to performance and therefore inspection. Porosity is a particularly important feature of 3D printed metals and its occurrence depends strongly on the input materials and on the processing conditions. The impact of data science on this area offers many possibilities such as the automatic recognition of materials origin and history. Finally the context for the course will be discussed, i.e. the rapidly growing penetration of the technology and its anticipated impact on manufacturing.

Course Website: <http://materials.cmu.edu>**27-796 Structure of Materials**

6 units

The skills and ideas necessary to understand the atomic structure of crystalline materials are presented. The objective is for the student to be able to describe crystal structures based on their symmetry (Bravais lattices, point groups and space groups) as well as packing configurations and to understand how diffraction is used to experimentally probe crystal structures.

27-797 Bonding of Materials

6 units

Models for cohesive forces in crystals are reviewed; both quantitative and phenomenological descriptions of secondary, ionic, metallic, and covalent bonds are discussed. A band structure language is developed starting from free electron and LCAO models of metals and covalently bonded crystals, respectively. 4 hrs lecture
Prerequisites: 33-234 or 33-225

27-798 Thermodynamics I

Fall: 6 units

The laws, concepts, and definitions of classical thermodynamics as well as selected relationships that matter exhibits will be covered and applied to gas, liquid and crystalline systems. Concepts and classifications of thermodynamic systems, variables and relationships will be presented and discussed. General criteria and conditions for equilibrium will be developed and applied. The basic concepts of statistical thermodynamics will be introduced and applied to the interpretation of entropy. Phase equilibria of unary systems and the nature of real gases will be explored.

27-799 Thermodynamics II

Fall: 6 units

The course will apply thermodynamic fundamentals covered in Thermodynamics I (27-798) to multi-component materials systems. The course will also cover equilibrium phase diagrams (binary and ternary), predominance diagrams, chemical reactions, thermodynamics of surfaces and electrochemistry.