Materials Science and Engineering

Materials are essential to the construction of any engineering structure, from the smallest integrated circuit to the largest bridge. In almost every technology, the performance, reliability, or cost is determined by the materials used. As a result, the drive to develop new materials and processes (or to improve existing ones) makes *materials science and engineering* one of the most important and dynamic engineering disciplines.

The central theme of materials science and engineering is that the relationships between the structure, properties, processing, and performance of materials are crucial to their function in engineering structures. *Materials scientists* seek to understand these fundamental relationships, and use this understanding to develop new ways for making materials or to synthesize new materials. *Materials engineers* design or select materials for particular applications and develop improved processing techniques. Since materials scientists and engineers must understand the properties of materials as well as their applications, the field is inherently interdisciplinary, drawing on aspects of almost every other engineering discipline as well as physics, chemistry, and, most recently, biology. Because the field encompasses so many different areas, it is often categorized according to types of materials (metals, ceramics, polymers, semiconductors) or to their applications (biomaterials, electronic materials, magnetic materials, or structural materials).

The department prepares students for successful careers in materials science and engineering, for advanced study in science or engineering, and for professional education in other fields. The goal of the undergraduate program is to provide a rigorous and comprehensive curriculum in materials science and engineering as well as in mathematics, basic sciences, humanities, and social sciences. Our low student-to-faculty ratio allows students close contact with faculty in both classroom and research environments, as well as with other students and researchers in the department. In the tradition of Johns Hopkins, all of our undergraduate students participate in research, often beginning in their sophomore year, working closely with faculty and graduate students.

In recognition that biomaterials and nanotechnology represent two of the most rapidly developing areas of materials science and engineering, the Department of Materials Science and Engineering offers challenging specializations in biomaterials or nanotechnology within its undergraduate program.

The field of *biomaterials* is concerned with the science and engineering of materials in biology and medicine. Man-made materials are increasingly used in applications such as drug delivery and gene therapy, scaffolds for tissue engineering, replacement body parts, and biomedical and surgical devices. Biomaterials is an inherently interdisciplinary field that requires deep understanding of the properties of materials in general, and the interactions of materials with the biological environment. The Biomaterials Track is designed to provide a firm grounding in the physics, chemistry, and biology of materials, as well as breadth in general engineering, mathematics, humanities, and social science. In addition, students are encouraged to gain hands-on experience in biomaterials research laboratories. The program seeks to educate students to reach the forefront of leadership in the field of biomaterials engineering. While the fundamental principles of materials science still apply, a complete understanding of biomaterials and their interactions with biological environments requires a greater degree of specialization than the standard undergraduate curriculum provides. In recognition of completion of the Biomaterials Track, a student may elect to have his or her academic transcript annotated to indicate a specialty in biomaterials.

Nanotechnology advances the utilization of materials and devices with extremely small dimensions. Nanotechnology is a visionary field, as micro and nanostructured devices impact all fields of engineering, from microelectronics (smaller, faster computer chips) to mechanical engineering (micromotors and actuators) to civil engineering ("smart", self-healing nanocomposite materials for buildings and bridges) to biomedical engineering (biosensors and tissue engineering). Materials Science is central to nanotechnology because the properties of materials can change dramatically when things are made extremely small. This observation isn't just that we need to measure such properties or develop new processing tools to fabricate nanodevices. Rather, our vision is that the wide (and sometimes unexpected!) variety of phenomena associated with nanostructured materials allow us to envision radically new devices and applications that can only be made with nanostructured materials. The Nanotechnology Track encompasses a curriculum designed to train students in the fundamental interdisciplinary principles of materials science including physics and chemistry, and also to expose students to cutting edge nanomaterials research, both in elective classes and in research laboratories. Students in the Nanotechnology Track will be well-prepared for successful careers in materials engineering across a wide range of disciplines. In recognition of completion of the Nanotechnology Track, a student may elect to have his or her academic transcript annotated to indicate a specialty in nanotechnology.

The graduate curriculum provides students with a broad yet thorough grounding in the fundamentals of materials science and engineering. After completing the core curriculum, students pursuing master's degrees take advanced courses that will allow them to work at the forefront of knowledge in their chosen specialty. Those desiring to conduct original research and advance the frontiers of knowledge pursue doctoral degrees. To this end, the department has an outstanding and wide-ranging research program, with particular emphasis on nanomaterials, thin films, metastable materials, biomaterials, computational materials science, and materials characterization.

The Faculty

Robert C. Cammarata, Professor (Chair): structure, properties, and processing of thin films and nanostructured materials, thermodynamics and mechanics of surfaces, mechanical behavior of materials, nanoindentation testing, stresses in thin films, novel electrochemical deposition methods, computer simulations.

Jonah Erlebacher, Assistant Professor: nanostructured materials, self-organization and pattern formation, computational materials science, kinetics of shape change, ion beam interactions with surfaces, ultra-high vacuum processing, nanoporous metals, fuel cells.

Robert E. Green Jr., Theophilus Halley Smoot Professor of Engineering: materials science, nondestructive characterization, ultrasonics, acoustic emission, X-ray diffraction, radiography, topography and tomography, synchrotron radiation, electro-optical systems, light-sound interactions, mechanical properties, thermography, sensors, process control.

Kalina Hristova, Assistant Professor: biomolecular materials, mimetics of cellular membranes, self-assembly of biological amphiphiles, protein-lipid interactions, protein synthesis, X-ray diffraction, fluorescence.

Todd C. Hufnagel, Associate Professor: structure and properties of metallic glasses, phase transformations, mechanical properties, X-ray diffraction, electron microscopy.

Howard E. Katz, Professor: organic, hybrid, and interfacial materials in electronic and photonic devices; organic materials synthesis, thin film fabrication and patterning; novel architectures for devices, sensors, and circuits; host-guest chemistry, material responses to high electric fields; organic nonlinear optics.

Jerome Kruger, Professor Emeritus: corrosion science and engineering, oxidation and passivation, ellipsometry, economics of corrosion.

Evan Ma, Professor: nonequilibrium processing, thermodynamics and kinetics of phase transformations, atomic level structures and polymorphs in metallic glasses, mechanical properties of amorphous and nanocrystalline metals, structural materials for microelectromechanical systems, thin films and surface modification.

Hai-Quan Mao, Assistant Professor: polymeric materials for tissue engineering, polymeric scaffolds for adult stem cell expansion, liver tissue engineering, polymeric materials for drug and gene delivery, liver targeted gene delivery, complex coacervation; microencapsulation, synthesis and characterization of biodegradable polymers, polyphosphoesters.

Theodore O. Poehler, Research Professor (Vice Provost for Research): quantum electronics, solid state physics, polymers and conducting organic compounds.

Robert B. Pond Sr., Professor Emeritus: physical metallurgy, materials science, solidification, superplasticity, solid mechanics.

Peter C. Searson, Professor: synthesis and characterization of nanostructured materials, thin films, metallization.

James B. Spicer, Professor: ultrafast phenomena, laser interactions with materials, nanostructured composite materials, elastic and anelastic materials properties, intelligent materials processing, near-field optical and microwave techniques, sensor physics, laser-based materials processing.

Timothy P. Weihs, Professor: self-propagating exothermic reactions and joining with reactive multilayer foils, processing and characterization of thin films, layered materials, and thin film reactions, mechanical testing of metals and biological materials.

Michael (Seungju) Yu, Assistant Professor: polymer chemistry, synthesis and application of protein-based materials, biomaterials for tissue engineering, nano-scale self-assembly of soft materials, biosynthesis of artificial proteins, liquid crystals.

Joint, Part-Time, and Visiting Appointments

D. Howard Fairbrother, Associate Professor (Chemistry): surface chemistry-chemistry of materials processing, synthesis, properties and characterization of multilayer thin films, radical surface reactions, environmental surface chemistry and remediation.

Kevin J. Hemker, Professor (Mechanical Engineering): mechanical behavior of materials, physical metallurgy, transmission electron microscopy, microstructure-mechanical properties relations in high temperature alloys, thermal barrier coatings, nanocrystalline materials and materials for MEMS.

Emanuel Horowitz, Professor (part-time): materials science, biomaterials, biocompatibility, metallo-organic compounds, polymers.

Joseph L. Katz, Professor (Chemical and Biomolecular Engineering): nucleation processes, formation of ceramic powders in flames, inhibiting scale formation, new proteomics tools.

Gerald Meyer, Professor: inorganic chemistry-photochemistry and electrochemistry of metal complexes and inorganic solids, light-induced electron and energy transfer, environmental science, bio-materials, artificial photosynthesis.

Edward P. Mueller, Lecturer (part-time); Consultant: biomaterials, surgical implants, anti-microbial materials.

Glenn Rahmoeller, Lecturer (part-time): applied ethics, use of utilitarian and deontological theories to analyze and solve controversial ethical issues confronting engineers.

Kathleen J. Stebe, Professor (Chemical and Biomolecular Engineering): surfactants, self-assembly, interfacial flows, dynamic surface tension,non-equilibrium interfaces.

David R. Veblen, Professor (Earth and Planetary Sciences): crystallography, transmission electron microscopy, X-ray diffraction, mineralogy.

Denis Wirtz, Professor (Chemical and Biomolecular Engineering): cell adhesion and migration, cell mechanics, cystoskeleton, receptor-ligand interactions, cancer, particle tracking, new proteomics tools.

Facilities

The teaching and research facilities of the Department of Materials Science and Engineering are located in Maryland and Krieger halls on the Homewood campus. Our central facilities include the Surface Analytical Laboratory, with advanced tools for the chemical characterization of solid surfaces; the Scanning Electron Microscopy Laboratory; the Laboratory for Thin Film Deposition; and facilities for sample preparation, optical microscopy, and mechanical testing. Individual research groups have established laboratories with advanced facilities for materials processing, nanotechnology, and materials characterization. Through collaboration with other departments and national laboratories, students and faculty also have access to a variety of other facilities necessary for world-class research.

Undergraduate Program

Mission Statement and Program Objectives

The Materials Science and Engineering faculty strives to maintain the Johns Hopkins University tradition: to train a small number of students of highest quality, whose impact on the scientific and engineering community is large compared with the size of the Department and the University. This institutional aspiration can only be realized with the success of our students as they pursue career directions beyond their time at Hopkins. Our degree program is designed to provide an optimum starting point for students with a diversity of career aspirations providing a solid foundation for future career development. As our graduates develop their paths forward, it is our intent that they will:

- Recognize, understand and further the evolving role that materials science and engineering plays in society.
- Pursue careers in materials science and engineering, or in fields that require an understanding of materials, using a broad, fundamental view of materials as well as a solid foundation in science and engineering.
- Engage in materials research and apply research methods in advancing a wide range of established and emerging technologies.
- Pursue graduate studies in materials and in related engineering fields or enter professional fields such as medicine or law.
- Communicate effectively in a range of technical and non-technical forums and engage productively in team-based efforts.
- Provide leadership and standards of ethical behavior in their professional roles that serve the scientific community, the engineering profession as well as broader segments of our society.

Requirements for the B.S. Degree

(See also General Requirements for Departmental Majors, page 46.)

The Department of Materials Science and Engineering offers a program leading to the Bachelor of Science degree. The B.S. Degree Program in

Materials Science and Engineering is accredited by the Accreditation Board for Engineering and Technology, Inc. (ABET). The student must meet the general University requirements for the chosen degree as well as the departmental requirements, and must complete the program approved by the student's adviser.

An anticipated individual program of study designed to meet the university and department requirements for the B.S. degree, as well as to reflect the student's interests should be filed as early as possible during the student's residence. The faculty adviser's signature is required on all course registration and course change forms. As changes are made in the program, it shall be the student's responsibility to see that a revised program is filed with the adviser. Each student must have an approved program on file no later than the semester before he/she expects to graduate.

To meet the course requirements for the B.S. degree in materials science and engineering, the student must complete a minimum of 128 credits, distributed as follows: 42 credits in materials science, 25 credits in basic natural sciences, 20 credits in mathematics or mathematical sciences, 15 credits in humanities and social sciences, 11 credits in basic engineering, and 15 credits of electives. Of these electives, 9 credits must be in natural sciences, mathematics, or engineering, and 6 credits are open electives to be chosen by the student. All courses must be passed with a letter grade of D or higher with the exception of open electives, which may be taken satisfactory/unsatisfactory. The 42 credits of materials science courses must be passed with a letter grade of C or higher.

In addition to the degree program in Materials Science and Engineering, students may elect complete specialized tracks in Biomaterials or Nanotechnology. Whether a student chooses to pursue studies following the standard program, the Biomaterials Track or the Nanotechnology Track, the coursework specified for the degree will provide a firm grounding in the principles of materials science and engineering. On completion of the undergraduate studies, students majoring in materials science and engineering will:

- Be well prepared for professional scientific and engineering practice, as well as for advanced study in materials science and engineering or other scientific, engineering or professional areas.
- Have acquired a solid grounding in the mathematics, chemistry, biology and the physics that are required for the solution of materials problems related to the structure, properties, processing and performance of materials.
- Utilize modern scientific, engineering and computer tools to analyze problems in materials science and engineering.
- Identify important scientific and engineering problems related to materials, and then design systems and processes as well as perform relevant experiments and interpret data to aid the solution of these problems.
- Learn to work both independently and in teams.
- Have obtained extensive experience in oral and written communication including science and engineering specific forms of communication such as technical reports, scientific notebooks and technical presentations of research.
- Be instilled with an appropriate appreciation of the broad need for life-long learning, the scope and meaning of professional responsibility and the relevance of engineering practice with regard to contemporary issues.

The specific requirements for the various program tracks are as follows.

Elective Requirements for Specialized Tracks. Students should note that some courses are not offered every year, and hence should plan their schedules accordingly. Substitutions relevant to a student's particular areas of interest may be made upon approval by the Materials Science and Engineering Undergraduate Program Committee.

Biomaterials Track. The Biomaterials Track is intended for those students with a focused interest in biomaterials. To satisfy the requirements of the Biomaterials Track, students must successfully complete a biomaterials senior design project, and also must complete the following courses with a grade of C or higher:

580.221 Molecules and Cells
510.407 Biomaterials II
510.431 Biocompatibility of Materials

Students must declare their intent to satisfy the requirements of the Biomaterials Track in Materials Science and Engineering by their 5th semester (1st semester junior year). Students may declare their intent in writing to their department advisers.

Nanotechnology Track. The Nanotechnology Track is intended for those students with a focused interest in nanomaterials. To satisfy the requirements of the Nanotechnology Track, students must successfully:

- complete a nanotechnology senior design project

- complete 510.440 Micro- and Nanostructured Materials and Devices with a grade of B or higher
- complete two advanced materials electives with a grade of C or higher selected from the following list:

  510.547 Materials Science of Thin Films
  540.440 Chemical Engineering for Micro and Nanotechnology
  540.438 Interfacial Phenomena in Nanotechnology
  530.487 Introduction to Microelectromechanical Systems (MEMS)
  530.495 Microfabrication Laboratory
  171.405 Introduction to Condensed Matter Physics

Students must declare their intent to satisfy the requirements of the Nanotechnology Track in Materials Science and Engineering by their 5th semester (1st semester junior year). Students may declare their intent in writing to their department advisers.

Below is a detailed description of the B.S. program (course credits in parentheses).

Materials Science (42 credits)

- **Ten core courses:**
  510.311 Structures of Materials (3)
  510.312 Physical Chemistry of Materials I: Thermodynamics (3)
  510.313 Mechanical Properties of Materials (3)
  510.314 Electronic Properties of Materials (3)
  510.315 Physical Chemistry of Materials II: Kinetics and Phase Transformations (3)
  510.316 Biomaterials I (3)
  510.428-429 Materials Science Lab I, II (3 ea.)
  510.433-434 Senior Design/Research (3 ea.)
  Four upper-level materials science electives
- (3 ea., 300-level or higher).

Courses in other departments with an emphasis on the structure, properties, or processing of materials may be counted as materials science electives. A list of approved electives appears in the department's Undergraduate Advising Manual (available from a student's academic adviser). All 400-level or higher classes required in the Biomaterials and Nanotechnology Tracks will be counted toward satisfying the upper-level materials science electives requirement.

Basic Sciences (25 credits)

171.101-102 Physics (4 ea.)
173.111-112 Physics Lab (1 ea.)
510.101 Intro to Materials Chemistry (3)*
or
030.101 Intro Chemistry (3)
030.105-106 Intro Chemistry Lab (1 ea.)
030.102 Intro Chemistry II (3)
030.205 Organic Chemistry I
030.225 Organic Chemistry Lab (3)

*Students may take 510.101 Introduction to Materials Chemistry or 030.101 Introductory Chemistry I to fulfill the Intro. Chem. I. requirement.

Mathematics or Mathematical Sciences (20 credits)

110.108, 109, 202 Calculus I, II, III (4 ea.)
110.201 Linear Algebra (4)
110.302 Differential Equations (4)

Basic Engineering (11 credits)

Students must complete **two** of the following:
520.213 Circuits (4)
530.201 Statics and Mechanics of Materials (4)
580.221 Molecules and Cells (4)

For the Biomaterials Track, 580.221 Molecules and Cells must be passed with a grade of C or higher.

Computer Programming (3)

Students must complete **one** of the following courses:
600.107 Intro to Programming in Java
600.109 Intro to Programming in C/C++
600.120 Intermediate Programming
500.200 Computing for Engineers and Scientists
530.106 Computing in Mechanical Engineering

Humanities and Social Sciences (15 credits)

- 15 credits of (H) or (S) electives

Science and Engineering Electives (9 credits)

- Two courses of upper level engineering, natural sciences or mathematics
- One course of unrestricted engineering, natural sciences or mathematics
- Upper level is 300 or higher

Unrestricted Electives (6 credits)

- 6 credits of electives

Sample Undergraduate Program for Materials Science and Engineering Traditional Track
(for a student beginning with Calculus I)

• **Year 1**

Fall

510.101	Intro to Materials Chemistry*	3
110.108	Calculus I	4
030.105	Intro. Chemistry Lab I	1
173.111	Physics Lab I	1
171.101	Physics I	4
Unrestricted Elective		3
	Total	16

Spring

030.102	Intro. Chem. I	3
030.106	Intro. Chem. Lab II	1
171.102	General Physics II	4
173.112	General Physics Lab II	1
110.109	Calculus II	4
Unrestricted Elective		3
	Total	16

• **Year 2**

Fall

510.311	Structures of Materials	3
030.205	Intro. Organic. Chem. I	4
030.225	Intro. Org. Chem. Lab	3
110.202	Calculus III	4
520.213	Circuits	4
	Total	18

Spring

510.313	Mechanical Prop. Mats.	3
510.314	Electronic Prop. Mats.	3
110.201	Linear Algebra	4
600.109	Intro. to Prog. C/C++	3
H/SS Elective		3
	Total	16

• **Year 3**

Fall

510.312	Phys. Chem. Mats I: Thermo.	3
510.316	Biomaterials I	3
510.428	Materials Science Lab I	3
530.201	Statics/Mechanics	4
H/SS Elective		3
	Total	16

Spring

510.315	Phys. Chem. Mats. II: Kinetics	3
510.429	Materials Science Lab II	3
110.302	Differential Equations	4
H/SS Elective		3
Math/Sci/Eng. Elective		3
	Total	16

• **Year 4**

Fall

510.433	Senior Design I	3
510.4xx	MSE elective	3
510.4xx	MSE elective	3
Math/Sci/Eng elective		3
H/SS Elective		3
	Total	15

Spring

510.434	Senior Design II	3
510.4xx	MSE elective	3
510.4xx	MSE elective	3
H/SS elective		3
Math/Sci/Eng elective		3
	Total	15

*Students may take 510.101 Introduction to Materials Chemistry or 030.101 Introductory Chemistry I to fulfill the Intro. Chem. I. requirement.

Further information is available in the department's undergraduate advising manual.

Undergraduates are encouraged to participate in the department's ongoing research programs. Interested students should consult with their advisers. Students registered for independent research (510.501-502) may receive up to 3 credits per semester.

Financial Aid

Scholarships and other sources of financial assistance for undergraduates are described under Admissions and Finances (see page 17). In addition, the faculty employ a number of undergraduates as laboratory assistants to help with various aspects of their individual research programs.

Graduate Programs

The Department of Materials Science and Engineering offers three different graduate degrees: the Ph.D., the M.S.E. (master of science in engineering), and the M.M.S.E. (master of materials science and engineering). The Ph.D. can be completed on either a full-time or part-time basis. In the part-time program, one year of full-time residency is required. The M.S.E. can be completed on either a full-time or a part-time basis.

The M.M.S.E. is a degree offered through the Engineering and Applied Science Programs for Professionals. The M.M.S.E. is a part-time terminal degree program, with classes primarily in the evening. Complete details are available in the Engineering and Applied Science Programs for Professionals catalog, which can be requested by contacting that office at 410-540-2960.

Admission

To be admitted to graduate study in the Department of Materials Science and Engineering, students must submit credentials sufficient to convince the faculty that they have the potential to complete successfully the requirements for a degree. Under the new GRE test, applicants should take the General Test package containing the Mathematical Reasoning test. The student's progress toward an advanced degree is assessed by the faculty adviser and the departmental graduate committee. Students are expected to remain in regular communication with their faculty adviser. The department believes that teaching experience is important to professional growth, and students are required to serve as a teaching assistant during their academic career.

Review of Student Performance

On an annual basis, the student's performance is reviewed by the graduate committee in consultation with the student's adviser to ensure that adequate progress is being made toward the completion of degree requirements. Only courses for which the student has received a grade of B- or better will be counted toward completion of course requirements, and an overall B average must be maintained. If a grade of C+ or lower is received, the student must repeat the course and achieve a grade of B- or better. Receipt of a letter grade of C+ or lower in two courses will normally be cause for dismissal from the program.

Independent research courses and part-time graduate program courses will not be counted toward completion of course requirements.

A graduate student pursuing a Ph.D. degree with the Department of Materials Science & Engineering (funded by the Department as a teaching assistant or research assistant) cannot enroll simultaneously in a master's program of another department, unless he/she receives written approvals from his/her adviser, the DMSE Graduate Program Committee, and the Department Chairman.

Requirements for the M.S.E. Degree

The degree of master of science in engineering is awarded subject to the recommendation of the student's adviser and departmental approval. All candidates for the degree must complete satisfactorily the following requirements:

- Three core courses in Materials Science and Engineering:
  510.601 Structures of Materials
  510.602 Thermodynamics of Materials
  510.603 Phase Transformations in Materials
- Any two of the following:
  510.604 Mechanical Properties of Materials
  510.605 Electronic, Optical, and Magnetic Properties of Materials
  510.606 Chemical and Biological Properties of Materials
- Three advanced (600-level or higher) courses in materials science and engineering or related fields.
- A research project reported as a written essay (see the dissertation/thesis instructions in the *Academic Information for Graduate Students* in this catalog for additional information). In lieu of an essay, with the concurrence of the faculty adviser, a student may submit to the Graduate Program Committee an article describing the research that has been published (or accepted for publication) in an archival, peer-reviewed technical journal. The student must be the primary author of the article. Upon review of the manuscript, the Graduate Program Committee may accept it in fulfillment of this requirement, or require the student to submit a formal written essay if the manuscript is unacceptable.

Requirements for the Ph.D. Degree

In general, candidates for the doctor of philosophy degree begin by satisfying the requirements for the M.S.E. Each Ph.D. candidate must successfully complete the following requirements:

- Six core courses in materials science and engineering:
  510.601 Structures of Materials
  510.602 Thermodynamics of Materials
  510.603 Phase Transformations in Materials
  510.604 Mechanical Properties of Materials
  510.605 Electronic, Optical, and Magnetic Properties of Materials
  510.606 Chemical and Biological Properties of Materials
- Four advanced (600-level or higher) courses in materials science and engineering or related fields.

In some cases, an adviser may require a student to complete additional course work. Students who have completed other graduate-level course work may petition the graduate program committee to waive up to two core courses (510.601-606) and up to two elective courses. Written requests for such waivers must be received by the graduate committee by the end of the first semester of matriculation.

- A comprehensive oral exam covering the areas of structure, thermodynamics, and phase transformations of materials, and the student's choice of one of the following areas: chemical and biological properties of materials; mechanical properties of materials; electrical, optical, and magnetic properties of materials. This exam is offered semiannually and may be taken prior to or during the student's second year. The student will have two opportunities to pass within a one year period. The examining committee will be composed of three tenured and/or tenure track departmental faculty members.

- An oral presentation of a dissertation proposal at a department seminar held before the end of the student's third year. A written version of the dissertation proposal must be presented to a three-member faculty committee two weeks prior to the oral presentation. One member of the committee shall be the faculty adviser; the other two members shall be selected in consultation with the faculty adviser. A brief closed discussion session between the student, adviser, and the other members of the faculty committee shall follow the presentation; additional private discussions may be required by one or more of the committee members.
- The completion of an original research project. Candidates must write a dissertation describing their work in detail. A public defense of the thesis before a committee of five faculty members (chosen by the Graduate Program Committee, with at least three members being from outside the department) is required, and will be followed by a closed final graduate board examination with the committee. The thesis will be approved by a majority vote of the committee. The thesis defense/oral examination must be scheduled for a date two months prior to any personal or university deadline for graduation. A complete draft of the dissertation must be presented to all of the committee members no later than two weeks before the defense. The dissertation in its final form must be read and signed by two members of the committee (the adviser and one other member).

The department must be satisfied that all academic requirements have been satisfied by the candidate before a recommendation to confer a Ph.D. degree is passed on to the University Graduate Board

Financial Aid

Fellowships of various forms are available for full-time graduate students, including tuition remission fellowships, teaching fellowships, and additional stipend fellowships.

Research assistantships are available to support full-time graduate students who work with individual professors on their research contracts and grants.

Undergraduate Courses

Introductory

510.101 (E,N) Introduction to Materials Chemistry
Basic principles of chemistry and how they apply to the behavior of materials in the solid state. The relationship between electronic structure, chemical bonding, and crystal structure is developed. Attention is given to characterization of atomic and molecular arrangements in crystalline and amorphous solids: metals, ceramics, semiconductors, and polymers (including proteins). Examples are drawn from industrial practice (including the environmental impact of chemical processes), from energy generation and storage (such as batteries and fuel cells), and from emerging technologies (such as biomaterials).
Katz 3 credits fall

510.104 (E,N,W) Introductory Lectures in Biomaterials
This course provides an introductory overview of the selection and use of materials in biological systems. During the first hour of each class period, a guest lecturer will discuss his area of expertise in the field of biomaterials. The lectures are of an introductory nature suitable for the nonspecialist and are open to freshmen. Topics to be included are selected from the areas of design of special materials for use in biological systems, the use of materials in biological systems, and the study of the properties of natural biological materials. The second hour is used for open discussion with the guest lecturer and the instructor on the specific topic for the day.
Horowitz, Mueller 3 credits spring

510.107 (E, N) Modern Alchemy
Can you really turn lead into gold? Converting common substances into useful materials that play important roles in today's technologies is the goal of many modern scientists and engineers. In this course, we will survey selected topics related to modern materials, the processes that are used to make them as well as the inspiration that led to their development. Topics will include the saga of electronic paper, the sticky stuff of gecko feet and the stretchy truth of metal rubber.
Spicer 3 credits fall

510.201 (E,N) Introduction to Engineering Materials
An introduction to the structure, properties, and processing of materials used in engineering applications. After beginning with the structure of materials on the atomic and microscopic scales, this course explores defects and

their role in determining materials properties, the thermodynamics and kinetics of phase transformations, and ways in which structure and properties can be controlled through processing. All major classes of materials (metals, ceramics, polymers, and semiconductors) are considered. Recommended for all engineering majors. Prerequisites: Introductory calculus, chemistry, and physics, or permission of instructor.
Spicer 3 credits spring

Intermediate

510.304 (S, W) Engineering Ethics
The course is built around actual case studies, supplemented by materials dealing with engineering professionalism, codes of ethics, and ethics philosophy. Students will learn professional responsibility, and how to design ethical responses within an organizational structure where one must balance career needs, legal and regulatory concerns, financial demands, and ambiguous and incomplete information. Case studies will be chosen to illustrate different kinds of ethical problems within different branches of engineering and different kinds of circumstances. These studies will be used to compare and contrast issues such as the choices and constraints faced by decision makers.
Rahmoeller 3 credits spring

The six course series, 510.311-316, is devoted to the fundamental principles and engineering applications of materials and the concepts necessary for the design of materials systems. This series is required for all majors in Materials Science and Engineering.

510.311 (E,N) Structure of Materials
First of the Introduction to Materials Science series, this course is devoted to study of the structure of materials. Lecture topics include bonding, atomic packing, crystal structure, imperfections in crystals, noncrystalline solids, and composite materials. Among the techniques treated are X-ray diffraction, stereographic projection, and optical and electron microscopy. Prerequisites: Calculus I, freshman/sophomore chemistry and physics, or permission of instructor.
Hristova 3 credits fall

510.312 (E,N) Physical Chemistry of Materials I: Thermodynamics
Second of the Introduction to Materials Science series, this course examines the principles of thermodynamics as they apply to materials. Topics include fundamental principles of thermodynamics, equilibrium in homogeneous and heterogeneous systems, thermodynamics of multicomponent systems, phase diagrams, thermodynamics of defects, and elementary statistical thermodynamics. Prerequisites: Calculus I and II, freshman/sophomore chemistry and physics, or permission of instructor.
Mao 3 credits fall

510.313 (E,N) Mechanical Properties of Materials
Third of the Introduction to Materials Science series, this course is devoted to a study of the mechanical properties of materials. Lecture topics include elasticity, anelasticity, plasticity, and fracture. The concept of dislocations and their interaction with other lattice defects is introduced. Among the materials studied are metals, polymers, ceramics, glasses, and composites. Prerequisite: 510.311.
Hufnagel 3 credits spring

510.314 (E,N) Electronic Properties of Materials
Fourth of the Introduction to Materials Science series, this course is devoted to a study of the electronic, optical and magnetic properties of materials. Lecture topics include electrical and thermal conductivity, thermoelectricity, transport phenomena, dielectric effects, piezoelectricity, and magnetic phenomena. Prerequisite: 510.311.
Ma 3 credits spring

510.315 (E,N) Physical Chemistry of Materials II: Kinetics and Phase Transformations
Fifth of the Introduction to Materials Science series, this course covers diffusion and phase transformations in materials. Topics include Fick's laws of diffusion, atomic theory of diffusion, diffusion in multicomponent systems, solidification, diffusional and diffusionless transformations, and interfacial phenomena. Prerequisite: 510.312
Cammarata 3 credits spring

510.316 (E, N) Biomaterials I
Sixth of the Introduction to Materials Science series, this course offers an overview of principles and properties of biomedical materials. Topics include properties of materials used in medicine, synthesis and properties of polymeric materials, polymeric biomaterials, natural and recombinant biomaterials, biodegradable materials, hydrogels, stimuli-sensitive materials, and characterizations of biomaterials. Prerequisites: Organic Chemistry I, Organic Chemistry Lab I
Yu 3 credits fall

510.401 (E,N) Materials in Service
Modern engineering materials are used in complex and expensive structures, creating an ever-increasing need to assure a safe service life prior to maintenance, replacement, or retirement. This course will describe the various types of environmental chemical attack (corrosion) resulting in degradation of materials, as well as the loss of mechanical stability caused by cyclic fatigue, other mechanical loading, and thermal cycling. In addition, we will discuss advanced nondestructive evaluation techniques for detecting fatigue, corrosion, and thermal damage in structures in service. Examples will be presented from aerospace, civil, medical, and military structures and devices.
Green 3 credits spring

510.402 (E,N) Structural Materials Engineering
This course provides a detailed look at materials used in applications where mechanical properties (such as strength, stiffness, or toughness) are of primary importance. The perspective of the class is to show how a desired set of properties can be achieved through an understanding of structure-properties-processing relationships. Examples include heat treatment of steels, metallic alloys

for orthopedic implants, ceramics for high temperature applications, and polymer composite materials.
Green 3 credits fall

510.403 (E,N) Materials Characterization
This course will describe a variety of techniques used to characterize the structure and composition of engineering materials, including metals, ceramics, polymers, composites and semiconductors. The emphasis will be on microstructural characterization techniques, including optical and electron microscopy, X-ray diffraction, and acoustic microscopy. Surface analytical techniques, including Auger electron spectroscopy, secondary ion mass spectroscopy, X-ray photoelectron spectroscopy, and Rutherford backscattering spectroscopy. Real-world examples of materials characterization will be presented throughout the course, including characterization of thin films, surfaces, interfaces, and single crystals.
Spicer 3 credits

510.404 (E,N) Micro- and Nano-Structured Materials and Devices
Almost every material's property changes with scale. We will examine ways to make micro- and nano-structured materials and discuss their mechanical, electrical, and chemical properties. Topics include the physics and chemistry of physical vapor deposition, thin film patterning, and microstructural characterization. Particular attention will be paid to current technologies including computer chips and memory, thin film sensors, diffusion barriers, protective coatings, and microelectromechanical (MEMS) devices. (Also listed as 510.644)
Erlebacher 3 credits

510.405 (E,N) Materials Physics
An overview of the principles of solid-state physics as they apply to engineering materials with an emphasis on nanomaterials. Topics include a study of physical phenomena in solids (such as thermal and electrical conductivity, thermal expansion, and elasticity) and their anisotropy in crystalline solids. Also covered are the fundamentals of quantum mechanics for an understanding of the properties of nanometer-scale electronic and optoelectronic materials structures.
Spicer 3 credits

510.407 (E,N) Biomaterials II
This course focuses on the interaction of biomaterials with the biological system and applications of biomaterials. Topics include host reactions to biomaterials and their evaluation, cell-biomaterials interaction, biomaterials for tissue engineering applications, biomaterials for controlled drug and gene delivery, biomaterials for cardiovascular applications, biomaterials for orthopedic applications, and biomaterials for artificial organs. Prerequisite: 510.316 (Also listed as 510.607)
Mao 3 credits spring

510.428 (E, N, W)Materials Science Laboratory I
This course focuses on characterizing the microstructure and mechanical properties of structural materials that are commonly used in modern technology. A group of A1 alloys, Ti alloys, carbon and alloy steels, and composite materials that are found, for example, in actual bicycles will be selected for examination. Their microstructures will be studied using optical metallography, scanning electron microscopy, X-ray diffraction, and transmission electron microscopy. The mechanical properties of these same materials will be characterized using tension, compression, impact, and hardness tests. The critical ability to vary microstructure and therefore properties through mechanical and heat treatments will also be demonstrated and investigated in the above materials.
Ma 3 credits fall

510.429 (E, N, W) Materials Science Laboratory II
This laboratory concentrates on the experimental investigation of electronic properties of materials using basic measurement techniques. Topics include thermal conductivity of metal alloys, electrical conductivity of metals/metal alloys and semiconductors, electronic behavior at infrared wavelengths, magnetic behavior of materials, carrier mobility in semiconductors, and the Hall effect in metals and semiconductors. Additional topics considered include basic processing of electronic materials and electronic device construction. Prerequisite: 510.311 or permission of instructor.
Katz 3 credits spring

510.431 (E,N) Biocompatibility of Materials
This course provides a detailed examination of the interaction of surgical implant materials (i.e., metals, polymers, ceramics, and composites) with the body. The effect of the physiological environment on the properties of implant materials is described as well as the cellular, tissue response to the implant. Concepts dealing with the design of materials with improved biocompatibility are explored. Prerequisite: 510.104 or 510.316, or permission of instructor.
Horowitz 3 credits spring

510.433 (E,N,W) Senior Design/Research Experience in Materials Science and Engineering I
This course is the first half of a two-semester sequence required for seniors majoring or double majoring in materials science and engineering. It is intended to provide a broad exposure to many aspects of planning and conducting independent research. During this semester, students join ongoing graduate research projects for a typical 10-12 hours per week of hands-on research. Classroom activities include discussions, followed by writing of research preproposals (white papers), proposals, status reports and lecture critiques of the weekly departmental research seminar. Prerequisites: 510.311-312, 510.428-429.
Hristova 3 credits fall

510.434 (E,N, W) Senior Design/Research Experience in Materials Science and Engineering II
This course is the second half of a two-semester sequence required for seniors majoring or double majoring in materials science and engineering. It is intended to provide a broad exposure to many aspects of planning and conducting independent research. During this semester, verbal reporting of project activities and status is emphasized, culminating in student talks presented to a special

session of students and faculty. Students also prepare a written final report summarizing their research results. Prerequisites: 510.311-312, 510.428-429, 510.433.
Hristova 3 credits spring

510.501-502 Research in Materials Science
Student participation in ongoing research activities. Research is conducted under the supervision of a faculty member and often in conjunction with other members of the research group.
Staff 1-3 credits fall/spring

510.503-504 Independent Study in Materials Science
Individual programs of study are worked out between students and the professor supervising their independent study project. Topics selected are those not formally listed as regular courses and include a considerable design component. Prerequisite: permission of instructor.
Staff 1-3 credits fall/spring

510.574 Intersession Research in Materials Science
Staff 1-3 credits

510.576 Intersession Independent Study
Staff 1-3 credits

510.597 Summer Research in Materials Science
Staff 1-3 credits

510.599 Summer Independent Study in Materials Science
Staff 1-3 credits

Cross-Listed

540.438/638 (E) Interfacial Phenomena in Nanotechnology
Nanotechnology is a new field that is still being defined, with concepts ranging from nanorobotics to nanomaterials. Whatever the outcome, engineering at the nanoscale will be dominated by surface science, as surface to volume ratios become large. Furthermore, self-assembly techniques, with which molecules can spontaneously assemble in ordered structures with nanometer length scales are ripe for exploitation to create new materials. In this class, the fundamentals of interfacial thermo-dynamics, interfacial interactions (e.g., van der Wall's interactions, electostatics, steric interactions), adsorption, self-assembly, and specific interactions will be covered with an emphasis on how to exploit these ideas in application in nanotechnology.
Stebe 3 credits

570.429 (E,N) Surface Effects in Technological Processes and Materials
Mechanical properties and stability of disperse systems and materials are considered in dependence on real microheterogeneous structure and physical/chemical surface phenomena determining particles cohesion. Concepts of modern physical/chemical mechanics are applied to achieving two cardinal goals: high stability and durability of materials including natural and living tissues, and low resistance during deformation and treatment, independence upon surrounding media and other environmental conditions. Prerequisites: 570.444 or general physics and chemistry.
Shchukin 3 credits fall

Graduate Courses

510.601 Structures of Materials
An introduction to the structure of inorganic and polymeric materials. Topics include the atomic scale structure of metals, alloys, ceramics, and semiconductors; structure of polymers; crystal defects; elementary crystallography; tensor properties of crystals; and an introduction to the uses of diffraction techniques (including X-ray diffraction and electron microscopy) in studying the structure of materials. Prerequisites: undergraduate chemistry, physics, and calculus or permission of instructor.
Cammarata

510.602 Thermodynamics of Materials
An introduction to the classical and statistical thermodynamics of materials. Topics include the zeroth law of thermodynamics; the first law (work, internal energy, heat, enthalpy, heat capacity); the second law (heat engines, Carnot cycle, Clausius inequality, entropy, absolute temperature); equilibrium of single component systems (free energy, thermodynamic potentials, virtual variations, chemical potential, phase changes); equilibrium of multicomponent systems and chemical thermodynamics; basics of statistical physics (single and multiple particle partition functions, configurational entropy, third law; statistical thermodynamics of solid solutions); and equilibrium composition-temperature phase diagrams. Prerequisites: undergraduate calculus, chemistry and physics or permission of instructor.
Hufnagel 3 hours fall

510.603 Phase Transformations in Materials
This course presents a unified treatment of the thermodynamics and kinetics of phase transformations from phenomenological and atomistic viewpoints. Phase transformations in condensed metal and nonmetal systems are discussed. Topics include absolute reaction rate theory, thermodynamics of irreversible processes, thermodynamics of surfaces and interfaces, chemical kinetics, nucleation and growth, spinodal decomposition, order-disorder transformations, diffusional transformations, martensitic transformations, coarsening, glass transition. Prerequisites: 510.601 and 510.602 or permission of instructor.
Erlebacher 3 hours spring

510.604 Mechanical Properties of Materials
An introduction to the properties and mechanisms that control the mechanical performance of materials. Topics include mechanical testing, tensor description of stress and strain, isotropic and anisotropic elasticity; plastic behavior of crystals, dislocation theory, mechanisms of microscopic plasticity, creep, fracture, and deformation and fracture of polymers. Prerequisite: 510.601 or permission of instructor.
Weihs 3 hours spring

510.605 Electronic, Optical, and Magnetic Properties of Materials
An overview of electrical, optical, and magnetic properties arising from the fundamental electronic and atomic structure of materials. Continuum materials properties are developed through examination of microscopic processes. Topics to be covered include quantum mechanical structure of solids including electronic band structure; electrical, thermal, and ionic conduction; response of materials to electromagnetic fields including dielectric permittivity, ferroelectric materials, and piezoelectricity; magnetic behavior including paramagnetism and ferromagnetism, magnetic permeability, magnetic domains, and magnetostriction; interactions of electromagnetic radiation with materials (absorption, reflection, refraction, and scattering, electro- and magneto-optic effects); and superconductivity. Emphasis will be placed on both fundamental principles and applications in contemporary materials technologies. Prerequisite: 510.601.
Spicer 3 hours spring

510.606 Chemical and Biological Properties of Materials
An introduction to the chemical and biological properties of organic and inorganic materials. Topics include an introduction to polymer science, polymer synthesis, chemical synthesis, and modification of inorganic materials, biomineralization, biosynthesis, and properties of natural materials (proteins, DNA, and polysaccharides), structure-property relationships in polymeric materials (synthetic polymers and structural proteins), and materials for biomedical applications. Prerequisites: undergraduate chemistry and biology or permission of instructor.
Yu 3 hours fall

510.607 (E,N) Biomaterials II
This course focuses on the interaction of biomaterials with the biological system and applications of biomaterials. Topics include host reactions to biomaterials and their evaluation, cell-biomaterials interaction, biomaterials for tissue engineering applications, biomaterials for controlled drug and gene delivery, biomaterials for cardiovascular applications, biomaterials for orthopedic applications, and biomaterials for artificial organs. Prerequisite: 510.316 (Also listed as 510.407)
Mao 3 credits spring

510.608 Electrochemistry
Thermodynamics of electrochemical interfaces, including electrochemical potential, the Nernst equation, ion-solvent interactions, and double layer theory. Charge transfer kinetics for activation and diffusion controlled processes. Analysis of kinetics at various electrodes, including redox reactions, metal-ion electrodes, and semiconductor electrodes. Electroanalytical techniques are discussed, including those related to bioelectrochemistry and semiconductor electrochemistry. Selected reactions of technological importance are evaluated, including the hydrogen evolution reaction, oxygen reduction, electrodeposition, and energy generation and storage. Undergraduate prerequisite: introductory chemistry or permission of instructor.
Searson 3 hours

510.609 Electrochemistry Lab
A series of laboratory experiments is used to illustrate the principles of electrochemistry. Prerequisite: 510.608 or permission of instructor.
Searson 3 hours

510.610 Chemistry and Physics of Semiconductor Surfaces
Basic principles of bonding, thermodynamics of crystals, surface energy, space charge effects, and potential distributions at phase boundaries are reviewed. Processes related to solid/liquid interfaces including electron transfer, photoeffects, adsorption, catalysis, etching, and oxide formation are covered. Relevant experimental methods including surface analytical techniques are reviewed. Examples of applications, including photovoltaic devices and solar cells, are discussed.
Searson 3 hours

510.611-612 Solid State Physics
An introduction to solid state physics for advanced undergraduates and graduate students in physical science and engineering. Topics include crystal structure of solids; band theory; thermal, optical, and electronic properties; transport and magnetic properties of metals, semiconductors, and insulators; and superconductivity. The concepts and applications of solid state principles in modern electronic, optical, and structural materials are discussed.
Poehler 3 hours

510.616 Applications of X-Ray Diffraction
This course introduces the student to crystal structure and what can be learned about materials by a variety of X-ray diffraction, radiographic, topographic, and tomographic techniques. The techniques covered include single crystal orientation, single crystal perfection, structure of polycrystalline materials, compositional analysis, and phase identification. An overview will be presented of research efforts illustrating how rapid X-ray diffraction imaging has served to study the plastic deformation of metals, grain boundary migration during recrystallization, and the structure of explosively loaded metals. The utility of X-ray topographic imaging for qualitative assessment of single crystals will be discussed using specific examples of topographic images acquired from nickel-based superalloy turbine blades, gallium-arsenide wafers, and quartz crystal resonators. Finally, the radiographic aspect of X-ray imaging will be considered with illustrations given of the application of computer-assisted X-ray tomography. The course will include both classroom lectures and laboratory exercises.
Green 3 hours

510.617 Advanced Topics in Biomaterials
This course reviews recent advances in biomaterials focusing on the design principles in polymeric materials and scaffolds. It will cover topics from molecular designs of polymeric biomaterials, materials surface engineering, processing of polymeric scaffolds, to manipulation of cellular behaviors through materials engineering. Specific examples in cell and tissue engineering, and drug and gene delivery will be discussed.
Mao 3 hours

510.619 Biopolymers Synthesis
In this course, we will review the current synthetic methods for preparing biopolymers of both synthetic and natural origin. The class will focus mainly on polypeptides and polysaccharides, but natural polyesters and polynucleotides (DNA and RNA) will be covered as well. Some of the main topics are; solid phase peptide synthesis, ring-opening polymerization for polypeptide synthesis, recombinant DNA and bacterial protein synthesis, bacterial production of biodegradable polyester, and chemical and biological engineering of polysaccharides.
Yu 3 hours

510.620 - Amorphous and Nanocrystalline Metals
Fundamentals of the structure and properties of amorphous and nanocrystalline metals. Models for structure of metallic glasses, structural characterization by scattering, EXAFS, and TEM; processing; glass-forming ability and crystallization kinetics; mechanical properties and deformation mechanisms; magnetic properties.
Hufnagel 3 hours

510.624 Theory of X-ray Diffraction
An introduction to diffraction theory and the uses of diffraction in structural characterization of materials. Topics include X-ray scattering by atoms, kinematic theory, Fourier series methods, diffraction from single crystals and polycrystalline materials, diffraction from multilayers, scattering by liquids and amorphous solids, small-angle scattering, dynamic theory. Prerequisite: 510.601.
Hufnagel 3 hours

510.636 Electronic Materials Science
Introduction to semiconductor device physics: band structure, current flow, capacitance, and recombination. Barriers and junctions, transistors, crystallography and crystalline defects. Processing: ion implantation, thermal oxidation, metallization, reaction kinetics, and diffusion barriers. Heterostructures and heteroepitaxy. Assembly and packaging.
Searson 3 hours

510.644 Micro- and Nano-Structured Materials and Devices
Almost every material's property changes with scale. We will examine ways to make micro- and nano-structured materials and discuss their mechanical, electrical, and chemical properties. Topics include the physics and chemistry of physical vapor deposition, thin film patterning, and microstructural characterization. Particular attention will be paid to current technologies including computer chips and memory, thin film sensors, diffusion barriers, protective coatings, and microelectromechanical devices (MEMS). (Also listed as 510.404)
Erlebacher 3 credits

510.650 Principles of Quantum Physical Interactions
Foundational quantum-mechanical study of nanometer-scale electronic and optoelectronic materials structures. Principles of quantum physics, stationary-state eigenfunctions and eigenvalues for one-dimensional potentials, interaction with the electromagnetic field, electronic conduction in solids, surface and interface effects, tunneling microscopy and spectroscopy. Prerequisites: 110.201 and 110.302 or equivalent, 510.311.
Spicer 3 hours

510.653 Advanced Statistical Thermodynamics
This course covers the advanced topics beyond those in the conventional thermodynamics and statistical thermodynamics. Topics include field theory, renormalization group, dynamic scaling, finite size effects, and non-equilibrium thermodynamics. Computation and its role in these topics are also covered. The applications of various theoretical methods and ideas in materials science and engineering are explored.
Staff 3 hours

510.657 Materials Science of Thin Films
The processing, structure, and properties of thin films are discussed emphasizing current areas of scientific and technological interest. Topics include elements of vacuum science and technology; chemical and physical vapor deposition processes; film growth and microstructure; chemical and microstructural characterization methods; epitaxy; mechanical properties such as internal stresses, adhesion, and strength; and technological applications such as superlattices, diffusion barriers, and protective coatings.
Weihs 3 hours

510.661 Alloy Stability and Phase Diagrams
This course examines the fundamentals of alloy theory and phase diagram modeling to understand the formation, stability, and evolution of alloy phases and microstructures. Topics to be covered include structures of intermediate alloy phases such as electron phases, Laves phases, interstitial phases, valency compounds, and superlattices; stability criteria of solid solutions and intermediate alloy phases, including Hume-Rothery rules, theories of ordering, electronic theories of solid solubility and alloy stability, and elastic instability; thermodynamic and kinetic analysis of phase and microstructural instability due to different driving forces: chemical, strain, interfacial, gradient, etc.; balance of kinetic stability and thermodynamic instability: formation of highly metastable or unstable phases far from equilibrium; and calculations of the phase stability ranges in terms of equilibrium or metastable binary or multi-component phase diagrams using CALPHAD modeling.
Ma 3 hours

510.665 Advanced Topics in Thermodynamics and Kinetics of Materials
Selected areas of thermodynamics and kinetics will be examined in depth with the aim of understanding the ideas and assumptions underlying results central to materials science. Attempts will be made to be as rigorous as possible without losing sight of the physical meanings. The theories and models obtained will be evaluated critically to determine their validity and limitations. Topics to be covered include classical formulations of the laws of thermodynamics, Carathéodory's formulation, relation of thermodynamics to statistical mechanics, Gibbs' ther-

modynamics of heterogeneous systems and of surfaces, thermodynamics of phase transitions, glass transition, theory of absolute reactions rates and thermodynamics of irreversible processes developed generally and applied to the chemical kinetics and diffusion, theory of nucleation (Volmer-Weber, Becker-Dùoring, Fisher-Turnbull), theory of growth (including instabilities during growth), Johnson-Mehl-Avrami kinetics of phase transformations, Lifshitz-Slyzov-Wagner kinetics of coarsening, spinodal decomposition. Prerequisite: 510.312 or 510.602 (or similar course covering thermodynamics).
Cammarata 3 hours

510.703 Great Papers in Materials Science
Classic papers in different disciplines of materials science are critically read with a goal of tracing intellectual and scientific progress, and relating such progress to modern developments. Students are required to read papers and develop presentations based on the paper's content.
Erlebacher, Cammarata 1 hour

510.731 Physical Metallurgy Seminar
Topics in physical metallurgy are discussed with extensive reference to both current and classic papers. Examples of possible topics include grain boundary structure and energetics (papers of Read and Shockley, Bollman), epitaxy and thin film growth (papers of van der Merwe, Matthews), spinodal decomposition (papers of Cahn, Hilliard, Hillert), thermodynamics of surfaces and interfaces (papers of Gibbs, Herring, Brooks, Cahn).
Cammarata 1 hour

510.733-734 Special Topics in Electronic/Optical-Material Interactions
Topics in this course concentrate on the understanding of interactions of electromagnetic fields with materials. These interactions range from the absorption of optical frequency waves to the excitation of materials using low frequency electromagnetic waves in the sub-megahertz regime. Emphasis is on studying representations and the corresponding analytical techniques used to model electromagnetic interactions with materials. Additionally, transduction techniques for the measurement of these interactions are discussed.
Spicer 2 hours

510.739-740 Surface Chemistry Seminar
Topics in surface chemistry and materials chemistry are discussed. The seminar covers various topics in these fields, including a review of the current literature. Prerequisite: permission of instructor.
Searson 1 hour

510.801-802 Materials Research Seminar
Staff 1 hour

510.803-804 Materials Science Seminar
Staff 1-2 hours

510.805-806 Selected Topics in Materials Science
Staff 3 hours

510.807-808 Graduate Research in Materials Science
Staff 3 hours