MATERIALS SCIENCE AND ENGINEERING

mccormick.northwestern.edu/materials-science

The discipline of materials science and engineering has expanded rapidly in response to growing demand for materials that make improved use of existing resources or are needed for new technologies. The program at Northwestern is broad based, offering educational and research opportunities in polymer science, ceramics, metallurgy, surface science, biomaterials, nanomaterials, and electronic materials. Engineers, scientists, and technologists who work on these different materials all basically apply the same scientific principles governing the interrelation of processing, structure, properties, and material performance. A key theme of the Northwestern program is the integration of these principles in the systematic design of new materials.

The department offers an undergraduate program leading to the BS degree and participates in the co-op and BS/MS programs. The curriculum centers on engineering and materials coursework, but also provides the flexibility to focus on different areas of concentration as described below. The student's educational experience is broadened by courses in the humanities, arts, sciences, and other areas of engineering. The undergraduate program culminates in the senior project, in which the student carries out a research/development project with a faculty member and his or her research group.

Students who complete the BS program will be well prepared for professional work or graduate study in the application, production, processing, or research and development of materials. Graduates find opportunities in many areas, since materials expertise is important in various engineering fields as well as in medicine, physics, and chemistry.

Areas of Concentration

The undergraduate program at Northwestern offers a close relationship between students and faculty. Every effort is made to tailor specific programs to needs and interests. Several broad areas of concentration are described below. Students are encouraged to create other areas that fit particular interests.

Biomaterials

The growth of biotechnology has stimulated interest in the interface of the life sciences and materials science. The field of Biomaterials spans three broad areas: biomedical implant materials to replace natural structures; biomimetic materials applying biological concepts to the design of new engineering materials; and application of materials science principles to the understanding of structure and function in biological systems.

Design and Manufacturing

This concentration is especially appropriate for those planning a career in industry, where engineers typically work in teams on projects requiring experience with design and manufacturing. It builds on the design content in the materials science curriculum and provides additional interdisciplinary design experience. The concentration also develops industrially relevant strengths in the areas of materials selection, computational tools, materials processing, and failure analysis.

Electronic Materials

As microelectronics enters the era of ultra-large-scale integration, materials scientists face new challenges in developing materials and processes for integrated circuits with components of nanometer dimensions. New scientific principles, materials fabrication techniques, and improved instrumentation will be needed to exploit electronic-level structure/property relations in devices and their components. New electronic materials must be developed to meet requirements in a growing range of application areas, such as spintronics, optical computing, and fuel cells.

Energy Materials

Materials play a key role in a variety of energy-related areas, including the search for new and efficient energy sources as well as energy storage and efficient energy utilization. Specific topics covered in this specialization include fuel cell materials, hydrogen generation and storage, solar energy conversion, lithium-ion battery materials, and lightweight energy-efficient structural materials.

Metals and Ceramics

The ability to design increasingly higher-strength alloys allows for lighter structures, and higher-temperature materials provide energy efficiency. Heat-treatable and toughened ceramics exploit advanced knowledge of solid-state phase transformations and reactions. Exciting developments are taking place in high-performance composite combinations of these and other materials for structural and electronic applications.

Nanomaterials

The area of nanomaterials, focusing on materials with sizes in the range of 1 to 100 nanometers, is an increasingly important research topic as nanotechnology industries develop. Examples of nanomaterials include ultrahigh-strength materials with nanometer-range structural features and structures designed and self-assembled atom by atom or molecule by molecule. Machines smaller than the tip of a pin can be built using either semiconductor materials processing or biologically inspired processing technology. This specialization is designed to give students the knowledge needed to work at the nanoscale, including design and synthesis, characterization, and theory/modeling/simulation of nanomaterials.

Polymeric Materials

Synthetic polymers offer the engineering community an ever-expanding array of materials having properties tailored by chemical and physical processing. New developments are opening up applications for polymers as high-strength, low-weight materials; optoelectronic components; and key materials in other revolutionary areas. The basic understanding of engineering properties in terms of multilevel microstructure is essential for the full utilization of polymers.

Surface Science

A solid communicates with the outside world through its surface. Wear, corrosion, and passivation are well-known surface processes. Chemical, electronic, and mechanical properties of materials depend on composition at surfaces and grain boundaries (internal surfaces), surface treatments, and the environment. The surface scientist must be able to not only determine the properties of surfaces and interfaces but also to control them.

Sustainable Materials

Many technologies that the materials, manufacturing, energy, and water sectors currently rely on to provide benefits to humanity are not designed

to last indefinitely. Redirection toward a more sustainable path is key. This concentration focuses on sustainability as it applies to materials and the manufacturing processes that convert them into a multitude of usable products. Students gain knowledge that bridges the domains of systems design and sustainable materials development and engineering.

Laboratories and Facilities

Materials science and engineering demands sophisticated experimental techniques for the preparation and characterization of advanced materials. The undergraduate program makes heavy use of state-of-the-art laboratory facilities in core courses, technical electives, and senior projects.

Materials preparation and processing equipment is available for all classes of materials, including an advanced crystal growth facility in a clean-room environment for preparing single crystals of metals, oxides, alkali halides, and semiconductors. Investigation of complex micro-structures employs a wide array of microscopy, diffraction, and microanalysis techniques. A unique combination of instruments (cold field–emission transmission electron microscope, atom-probe field-ion microscopes, scanning tunneling microscopes) provides atomic resolution imaging and chemical analysis. These are complemented by an extensive surface analytical laboratory. Characterization of material properties employs an advanced mechanical testing facility featuring static and dynamic loading under controlled temperature and environment. Specialized facilities measure electrical, spectroscopic, magnetic, and photonic properties. Computer laboratories and a design studio address thermodynamic modeling and simulation of microstructural evolution, with application in materials design.

Program of Study

- Materials Science and Engineering Degree (https://catalogs.northwestern.edu/undergraduate/engineering-applied-science/materials-science-engineering/materials-science-engineering-degree/)

MAT_SCI 190-0 MS & E Freshman Seminar (1 Unit) Laboratory-oriented, with research projects emphasizing use of the scanning electron microscope and other modern apparatus; correlation of structure with other properties of materials. Lectures, laboratory.

MAT_SCI 195-0 Introductory Special Topics in Materials Science and Engineering (1 Unit) Introductory topics suggested by students or faculty and approved by the department.

MAT_SCI 201-0 Introduction to Materials Science and Engineering Principles (1 Unit) Basic concepts of Materials Science and Engineering: bonding, crystal structure, defects in solids, phase diagrams, and development of microstructures. Processing/structure/property/performance relationships underlying the behavior of metals, ceramics, polymers, semiconductors, and composites. Mechanical, electrical, and chemical properties of engineering materials. Broadly, how materials' performance influences technological development, the economy, the environment, and society. Not to be taken for credit with or after MAT_SCI 301-0. Prerequisite: CHEM 131-0, CHEM 151-0, CHEM 171-0, CHEM 1X1, CHEM 215, or CHEM 217.

MAT_SCI 301-0 Introduction to Materials Science and Engineering Principles (1 Unit) Basic concepts of Materials Science and Engineering: bonding, crystal structure, defects in solids, phase diagrams, and development of microstructures. Processing/structure/property/performance relationships underlying the behavior of metals, ceramics, polymers, semiconductors, and composites. Mechanical, electrical, and chemical properties of engineering materials. Broadly, how materials' performance influences technological development, the economy, the environment, and society. Prerequisites: CHEM 131-0, CHEM 151-0, CHEM 171-0, CHEM 1X1, CHEM 215, or CHEM 217;major in materials science and engineering or chemical and biological engineering; concurrent enrollment in MAT_SCI 302.

MAT_SCI 302-0 Introduction to Materials Laboratories (0.34 Unit)
Lab for students taking MAT_SCI 301. Topics related to: Bonding, crystal structure and defects in solids. Phase diagrams in condensed matter systems. Equilibrium and nonequilibrium development of microstructures. Processing/structure/property/performance relationships underlying behavior of metals, ceramics, polymers, and composites. Mechanical, electrical, chemical properties of engineering materials. To be taken concurrently with MAT_SCI 301-0.

MAT_SCI 314-0 Thermodynamics of Materials (1 Unit)
Classical and statistical thermodynamics; entropy and energy functions in liquid and solid solutions, and their applications to phase equilibria. Lectures, problem solving. Materials science and engineering degree candidates may not receive credit for 314 with or after CHEM 342-1. Prerequisite: CHEM 132-0, CHEM 152-0, CHEM 172-0 or CHEM 1X2; MATH 228-1 or MATH 230-1; or PHYSICS 135-1 or equivalent.

MAT_SCI 315-0 Phase Equilibria & Diffusion of Materials (1 Unit)
Application of thermodynamics to ternary phase equilibria. Defects and diffusion in solids. Interdiffusion. Short-circuit diffusion. Defects and transport in ionic solids. Lectures, problem solving, and laboratory. Prerequisite: MAT_SCI 201-0 or MAT_SCI 301-0 or equivalent and MAT_SCI 314-0 or equivalent.

MAT_SCI 316-1 Microstructural Dynamics (1 Unit)
Principles underlying development of microstructures. Defects, diffusion, phase transformations, nucleation and growth, thermal and mechanical treatment of materials. Lectures, laboratory.
Prerequisite: MAT_SCI 315-0 or equivalent.

MAT_SCI 316-2 Microstructural Dynamics (1 Unit)
Principles underlying development of microstructures. Defects, diffusion, phase transformations, nucleation and growth, thermal and mechanical treatment of materials. Lectures, laboratory.
Prerequisite: MAT_SCI 316-1 or instructor consent.

MAT_SCI 318-0 Materials Selection (1 Unit)
Methods of specifying materials and the processes for making them in the context of a given application. Service performance of materials based on their physical and chemical properties. Case studies and use of high-level databases.
Prerequisite: MAT_SCI 201-0 or equivalent.

MAT_SCI 331-0 Soft Materials (1 Unit)
Different kinds of polymeric materials. Relationships between structure and physical properties; rubber elasticity, the glassy state, crystallinity in polymers. Lectures, laboratory.
Prerequisites: MAT_SCI 301-0 or equivalent; MAT_SCI 314-0 or CHEM 342-1; MAT_SCI 316-1 and MAT_SCI 316-2 highly recommended.

MAT_SCI 332-0 Mechanical Behavior of Solids (1 Unit)
Plastic deformation and fracture of metals, ceramics, and polymeric materials; structure/property relations. Role of imperfections, state of stress, temperatures, strain rate. Lectures, laboratory.
Prerequisites: MAT_SCI 316-1; MAT_SCI 316-2 (may be taken concurrently) or consent of instructor.

MAT_SCI 336-0 Synthetic Design of New Materials (1 Unit)
The design of new materials targeting important technological functions through processes requiring chemical reactions, synthesis of molecules,

and molecular design for self-assembly and 3D printing. Fundamental principles and design strategies, including polymerization, biosynthesis and biocompatibility, design of molecular precursors for electronic materials and ceramics, synthesis of nanomaterials, composite and hierarchical structures.
Prerequisite: junior standing in materials science and engineering or consent of instructor.

MAT_SCI 340-0 Ceramic Processing (1 Unit)
Steps in production of fired ceramic articles. Powder preparation and characterization, compact formation, slip casting, extrusion and injection molding; firing, liquid-phase and solid-state sintering. Lectures, laboratory.
Prerequisite: MAT_SCI 316-1 or equivalent.

MAT_SCI 345-0 Corrosion of Materials (1 Unit)
Corrosion is the deterioration of materials due to electrochemical attack by the environment, driven by the flow of electrons and ions. We will develop fundamental understanding of these electrochemical reactions at equilibrium and their behavior away from equilibrium. This will be followed by the exploration of various corrosion phenomena, their scientific and quantitative basis, and how we can mitigate the adverse effects of corrosion. We will also learn that corrosion can be good and plays an integral role in developing sustainable energy resources and maintaining our infrastructure.
Prerequisite: MAT_SCI 201-0 or MAT_SCI 301-0 or consent of instructor.

MAT_SCI 351-1 Introductory Physics of Materials (1 Unit)
Quantum mechanics; applications to materials and engineering. Band structures and cohesive energy; thermal behavior; electrical conduction; semiconductors; amorphous semiconductors; magnetic behavior of materials; liquid crystals. Lectures, laboratory, problem solving.
Prerequisites: MAT_SCI 301-0 or equivalent or consent of instructor; GEN_ENG 205-4 or equivalent; PHYSICS 135-2, PHYSICS 135-3; MAT_SCI 351-1 is prerequisite for MAT_SCI 351-2.

MAT_SCI 351-2 Introductory Physics of Materials (1 Unit)
Quantum mechanics; applications to materials and engineering. Band structures and cohesive energy; thermal behavior; electrical conduction; semiconductors; amorphous semiconductors; magnetic behavior of materials; liquid crystals. Lectures, laboratory, problem solving.
Prerequisites: MAT_SCI 301-0 or equivalent or consent of instructor; GEN_ENG 205-4 or equivalent; PHYSICS 135-2, PHYSICS 135-3; MAT_SCI 351-1 is prerequisite for MAT_SCI 351-2.

MAT_SCI 353-0 Bioelectronics (1 Unit)
Development and design of sensors, stimulators, and their medical devices for biointegrated electronics. Materials design and fabrication of passive and active components for sensitive, multimodal, and robust wearable and implantable devices.

MAT_SCI 354-0 Bioelectronics Lab (1 Unit)
Laboratories focused on the practical implementation, instrumentation, and fabrication of wearables and skinsensing. Applications range from vital sign monitoring to rehabilitation.
Prerequisites: BMD_ENG 353 or MAT_SCI 353. Concurrent enrollment is acceptable.

MAT_SCI 355-0 Electronic Materials (1 Unit)
Principles, models, and characterization of semiconductor materials. Crystal growth and doping. Diffusion, epitaxy, and monolithic processes. Current transport, non-equilibrium processes, thin films, low-mobility materials, and interfaces.
Prerequisite: MAT_SCI 316-1 or consent of instructor.

MAT_SCI 357-0 Nanomagnetic Materials for Information Storage (1 Unit)
Overview of materials used for magnetic data storage and of the recording and read processes. Information storage systems, such as optical, solid-state, and probe. Theoretical background for understanding the four energy terms that control the properties of magnetic materials when they are patterned at the nanoscale.

MAT_SCI 358-0 Modeling and Simulation in Materials Science and Engineering (1 Unit)
The course covers the essential methods and principles for modeling and simulating the structure, properties, and behavior of materials. It focuses on constructing models and identifying approaches to test either theoretical descriptions or experimental observations of materials phenomena on a computer. The course balances breadth versus depth of topics with the goal of producing researchers literate in computational materials science and its applicability across different length scales. Students will construct structure-property models of atomic assemblies, molecules, and solids using first-principles electronic structure (such as density-functional theory), deterministic (molecular dynamics), statistical methods (Monte Carlo and (Un)Supervised Learning), and finite elements models. Computational laboratories will give students extensive hands-on experience with several powerful modern materials modeling codes.
Prerequisite: MAT_SCI 314-0, MAT_SCI 315-0, MAT_SCI 316-1, and MAT_SCI 351-1.

MAT_SCI 360-0 Introduction to Electron Microscopy (1 Unit)
Theories and practice involved in application of scanning electron microscopy and transmission electron microscopy. Lectures, laboratory. Primarily for undergraduates and for graduate students in other departments.
Prerequisites: MAT_SCI 301-0; PHYSICS 135-2, PHYSICS 135-3 or equivalent.

MAT_SCI 361-0 Crystallography & Diffraction (1 Unit)
Elementary crystallography. Basic diffraction theory; reciprocal space. Applications to structure analysis, preferred orientation. Film and counter techniques. Lectures, laboratory.
Prerequisites: GEN_ENG 205-4 or equivalent; PHYSICS 135-2, PHYSICS 135-3.

MAT_SCI 371-0 Biominerals: Hierarchical Architecture & Function (1 Unit)
How biologically based processing of mineralorganic composites used by living organisms inspires new approaches to materials synthesis in many critical applications-locomotion (bones), defense (shells), and sensing (light, acceleration, magnetic fields).
Prerequisite: MAT_SCI 316-2 or equivalent, or consent of instructor.

MAT_SCI 376-0 Nanomaterials (1 Unit)
Introduction to structure-property relationships of materials processed at the nanometer scale. Highly interdisciplinary course appropriate for undergraduate and graduate students in other departments.
Prerequisite: MAT_SCI 351-1 or consent of instructor.

MAT_SCI 377-0 Supramolecular Design of Materials and Nanostructures (1 Unit) Introduction to frontier research at the interface of chemistry and materials science.

MAT_SCI 380-0 Intro Surface Science & Spectroscopy (1 Unit)
Surface spectroscopy, including Auger spectroscopy, photoemission, and LEED. Surface dynamics and thermodynamics. Electronic properties of surfaces and interfaces. Gas-surface interactions.
Prerequisite: MAT_SCI 351-1 or equivalent.

MAT_SCI 381-0 Materials for Energy-Efficient Technology (1 Unit)
A materials science approach to the challenges of energy efficient technology: energy content of materials; advanced materials for energy

harvesting, transmission, storage, and conversion; materials for energy efficient transportation and housing. Term paper and oral presentation. Prerequisite: MAT_SCI 201-0, MAT_SCI 301-0, or consent of instructor.

MAT_SCI 382-0 Electrochemical Energy Materials and Devices (1 Unit)
Thermodynamics and kinetics of electrochemical processes. Materials for fuel cells, batteries, and electrochemical capacitors, including electrolytes and electrodes. Electrical and mass transport. Effect of microstructure. Electrochemical characterization. Device configurations. Prerequisite: senior standing or consent of instructor.

MAT_SCI 385-0 Electronic and Thermal Properties of Materials (1 Unit)
Thermoelectric Devices. Solid-state electronic structure from a solid-state chemistry perspective, phonons in complex materials, electronic and thermal transport at room temperature and above (semi-classical) of metals, semiconductors and some insulators. Familiarity with quantum mechanics and the concept of density-of-states for electrons and phonons. MAT_SCI 351-1 or equivalent is recommended but not required.

MAT_SCI 390-1 Process and Experimental Design (1 Unit)
This course introduces students to materials processing techniques used in research and industrial settings and the approaches scientists and engineers take to optimize processing-structure-property-performance relationships. Students are introduced to the systems design approach and design of experiments in order to define their own problems in materials science and engineering. Students develop core competencies in problem identification, experimental decision making, and technical communication.
Prerequisite: MatSci 316-2 and MatSci 351-2 or consent of instructor. MatSci 331 is recommended. MatSci 390-1 is a prerequisite for MatSci 390-2.

MAT_SCI 390-2 Materials Design (1 Unit)
In this course, students apply a systems design approach to address contemporary problems in materials science and engineering. Using fundamental materials science principles, students implement their own methods and approaches to investigate processing-structure-properties-performance relationships. Students develop core competencies in project management, data collection and analysis, experimental decision making, and technical communication.
Prerequisites: MAR_SCI 316-2 and MAT_SCI 351-2 or consent of instructor. MAT_SCI 331-0 and MAT_SCI 332-0 are recommended. MAT_SCI 390-1 is a prerequisite for MAT_SCI 390-2.

MAT_SCI 394-0 Honors Project in Materials Science (1 Unit)
Independent study and/or research linked to MAT_SCI 396-1 and MAT_SCI 396-2. Comprehensive report on a specific area of modern materials science and engineering. Prerequisite: registration in department honors program.

MAT_SCI 395-0 Special Topics in Materials Science and Engineering (1 Unit)
Topics suggested by students or faculty and approved by the department.

MAT_SCI 396-1 Senior Project in Materials Science and Engineering (1 Unit) To be taken in two consecutive quarters. Independent basic or applied research project, conceived and performed under the direction of a department faculty member. Prerequisite: senior standing in the materials science and engineering or materials science program.

MAT_SCI 396-2 Senior Project in Materials Science and Engineering (1 Unit) To be taken in two consecutive quarters. Independent basic or applied research project, conceived and performed under the direction of a department faculty member. Prerequisite: senior standing in the materials science and engineering or materials science program.

MAT_SCI 397-0 Special Topics in Materials Science and Engineering (0.34 Unit)
Special Topics in Materials Science and Engineering; laboratory emphasis.

MAT_SCI 399-0 Projects (1 Unit) Individual problems, including library and design work; comprehensive report on a specific phase of modern materials science. Credit to be arranged.