

MATERIALS SCIENCE AND ENGINEERING

<http://materials.jhu.edu/>

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 among the structures, 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 synthesize new materials or develop new processes for producing existing ones. 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 and draws 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, and 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. The student is encouraged to proceed at their own rate and to participate in interdisciplinary, interdepartmental, and interschool programs. 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.

Biomaterials

The field of biomaterials is concerned with the science and engineering of materials in biology and medicine. Engineering 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 concentration 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 concentration, a student may elect to have their academic transcript annotated to indicate a specialty in biomaterials.

Nanotechnology

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 is not simply 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 concentration 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 the forefront of nanomaterials research through elective classes as well as research laboratories. Students in the Nanotechnology concentration will be well-prepared for successful careers in materials engineering across a wide range of disciplines. In recognition of completion of the Nanotechnology concentration, a student may elect to have their academic transcript annotated to indicate a specialty in nanotechnology.

Graduate Curriculum

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 and PhD 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 a master's thesis and/or PhD thesis. 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.

Facilities

The teaching and research facilities of the Department of Materials Science and Engineering are located in Maryland Hall, Krieger Hall, and Croft Hall on the Homewood campus. The Department also administers the Materials Characterization and Processing Facility, which houses advanced tools for electron microscopy, X-ray diffraction, facilities for sample preparation, optical microscopy, and mechanical testing, as well as many other advanced materials tools for research and education. 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 that enable further cutting-edge advances in their research fields.

Undergraduate Programs

Materials play a central role in the performance and reliability of virtually every technology and living organism. 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. Materials scientists seek to understand these fundamental relationships, synthesize new materials, develop improved processes for making materials, and understand the role of materials in the functioning of biological organisms. The wide range of problems addressed makes materials science one of the most highly interdisciplinary and dynamic engineering disciplines.

The Materials Science & Engineering faculty strives to maintain the Johns Hopkins University tradition of training a small number of students of the highest quality. We measure our success by the impact our graduates have on the scientific and engineering communities. Our program is designed to provide a solid foundation for future career development for students with diverse career aspirations.

Accreditation

The BS program in Materials Science and Engineering is accredited by the Engineering Accreditation Commission of ABET (<https://www.abet.org/>), under the General Criteria and the Program Criteria for Materials (1), Metallurgical (2), Ceramics (3) and Similarly Named Engineering Programs.

Financial Aid

Information about scholarships and other sources of financial assistance for undergraduates is available from the Office of Student Financial Support (<https://finaid.jhu.edu/>). In addition, the faculty employs 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 (DMSE) offers three graduate degrees: the PhD (Doctor of Philosophy), the M.S.E. (Master of Science in Engineering), and the M.M.S.E. (Master of Materials Science and Engineering). After meeting the two-semester residency requirement, the PhD and the M.S.E. programs can be completed on either a full-time or part-time basis (with advanced approval from the program, the Dean's Office, and as relevant, in compliance with visa/immigration enrollment stipulations). Financial aid is available only for students matriculating as full-time, resident PhD students. The M.S.E. degree may be completed either with or without an essay, as described below.

Hopkins undergraduate students are encouraged to consider completing both the B.S. degree and the M.S.E. degree in a total of five years. This five-year, dual degree option offers additional preparation for the pursuit of PhD programs and careers in materials science and engineering. Students are encouraged to consult their undergraduate advisors to gain information on M.S.E. programs at Hopkins, as well as third- and fourth-year course selections best suited to the pursuit of the M.S.E. degree.

The M.M.S.E. is a terminal master's degree offered through Johns Hopkins Engineering for Professionals (EP) of the Whiting School of Engineering. The degree program consists of 10 courses offered primarily remotely/asynchronously. Students interested in this program should apply through EP (<https://ep.jhu.edu/>).

Financial Aid

Merit and need-based grants, work-study opportunities, and federal student loans to undergraduate students are administered by the Office of Student Financial Support (<http://www.jhu.edu/finaid/>). This office also provides access to federal student loans and work-study opportunities for graduate students.

Cost of Attendance information can be found here (<https://studentaffairs.jhu.edu/student-accounts/tuition-fees/>). A list of estimated expenses for graduate study is available on the Homewood Graduate Student Affairs (<https://homewoodgrad.jhu.edu/life-at-hopkins/costsandfunding/>) website.

Master's Degree Students

Students who have graduated with a Johns Hopkins University undergraduate degree automatically earn a Dean's Master's Fellowship covering half of the tuition for every semester (fall/spring) of full-time enrollment in a WSE master's degree program, provided they have either: (a) completed eight full-time semesters of study at Johns Hopkins, or (b) have not been enrolled at JHU for at least one year.

Students pursuing a combined bachelor's and master's degree who have not yet completed eight full-time semesters of study at JHU, and have retained undergraduate status, are eligible to continue to apply for undergraduate financial aid through the Office of Student Financial Services.

- GoGrad Graduate Financial Aid (<http://www.gograd.org/financial-aid/>)
- GoGrad Graduate Scholarships (<http://www.gograd.org/financial-aid/scholarships/>)
- College Scholarships for Black Students (<https://www.affordablecollegesonline.org/college-resource-center/black-students-college-scholarships/>)

Students who have completed all the coursework, other than research, required for an MSE degree in Materials Science and Engineering and are in good academic standing may be eligible for a Master's Research Scholarship. Please see the following form for details.

- Materials Research Scholarship with application (<https://engineering.jhu.edu/materials/wp-content/uploads/2021/11/Materials-Research-Scholarship-with-application.pdf>)

PhD Students

WSE PhD students are fully funded (tuition, health insurance and stipend) for the duration of their PhD program while they are in a fulltime, resident status.

Qualified PhD students are strongly encouraged to apply for external fellowships. These prestigious awards provide significant flexibility in the choice of advisor and research program. Examples include:

- National Science Foundation Graduate Research Fellowship (<http://www.nsfgrfp.org/>)

- National Defense Science and Engineering Graduate Fellowship (<https://ndseg.sysplus.com/>)
- Hertz Foundation Applied Science Fellowship (<http://www.hertzfoundation.org/>)
- Computational Sciences Graduate Fellowship (<http://www.krellinst.org/csgf/>)
- Stewardship Science Graduate Fellowship (<http://www.krellinst.org/ssgf/>)

Programs

- Materials Science and Engineering, Bachelor of Science (<https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/materials-science-engineering/materials-engineering-bachelor-science/>)
- Materials Science and Engineering, Master of Science in Engineering (<https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/materials-science-engineering/materials-science-engineering-master/>)
- Materials Science and Engineering, PhD (<https://e-catalogue.jhu.edu/engineering/full-time-residential-programs/degree-programs/materials-science-engineering/materials-science-engineering-phd/>)

For current course information and registration go to <https://sis.jhu.edu/classes/>

Courses

EN.510.106. Foundations of Materials Science & Engineering. 3 Credits.

Basic principles of materials science and engineering 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). The processing and synthesis of these different categories of materials. Basics about the phase diagrams of alloys and mass transport in phase transformations. Introduction to materials behavior including their mechanical, chemical, electronic, magnetic, optical and biological properties.

Distribution Area: Engineering, Natural Sciences

EN.510.135. MSE Design Team I. 3 Credits.

This course is the first half of a two-semester course sequence for freshmen majoring or double majoring in materials science and engineering (MSE). This course provides a broad exposure to various aspects of planning and conducting independent research in a team setting (3 to 6 students on each team). In this course, MSE freshmen working with a team leader and seniors on the team, apply their general knowledge in MSE to develop the solution to open-ended problems. Materials Science & Engineering Freshman Only. Recommended Course Background: EN.510.106, EN.510.109, or equivalent courses. *The team will meet 150 minutes per week at a time to be designated by the instructor.

Distribution Area: Engineering, Natural Sciences

EN.510.136. MSE Design Team I. 3 Credits.

This course is the second half of a two-semester course sequence for freshmen majoring or double majoring in materials science and engineering (MSE). This course provides a broad exposure to various aspects of planning and conducting independent research in a team setting (3 to 6 students on each team). In this course, MSE freshmen working with a team leader and seniors on the team, apply their general knowledge in MSE to develop the solution to open-ended problems. Materials Science & Engineering Freshman Only. Recommended Course Background: EN.510.106, EN.510.109, or equivalent courses. *The team will meet 150 minutes per week at a time to be designated by the instructor.

Distribution Area: Engineering, Natural Sciences

EN.510.235. MSE Design Team I. 3 Credits.

This course is the first half of a two-semester course sequence for sophomores majoring or double majoring in materials science and engineering (MSE). This course provides a broad exposure to various aspects of planning and conducting independent research in a team setting (3 to 6 students on each team). In this course, MSE freshmen working with a team leader and seniors on the team, apply their general knowledge in MSE to develop the solution to open-ended problems. Materials Science & Engineering Sophomores Only. Recommended Course Background: EN.510.106, EN.510.109, or equivalent courses. *The team will meet 150 minutes per week at a time to be designated by the instructor.

EN.510.236. MSE Design Team I. 3 Credits.

This course is the second half of a two-semester course sequence for sophomores majoring or double majoring in materials science and engineering (MSE). This course provides a broad exposure to various aspects of planning and conducting independent research in a team setting (3 to 6 students on each team). In this course, MSE freshmen working with a team leader and seniors on the team, apply their general knowledge in MSE to develop the solution to open-ended problems. Materials Science & Engineering Sophomores Only. Recommended Course Background: EN.510.106, EN.510.109, or equivalent courses. *The team will meet 150 minutes per week at a time to be designated by the instructor.

Distribution Area: Engineering, Natural Sciences

EN.510.311. Structure Of Materials. 3 Credits.

First of the Introduction to Materials Science series, this course seeks to develop an understanding of the structure of materials starting at the atomic scale and building up to macroscopic structures. Topics include bonding, crystal structures, crystalline defects, symmetry and crystallography, microstructure, liquids and amorphous solids, diffraction, molecular solids and polymers, liquid crystals, amphiphilic materials, and colloids. This course contains computational modules; some prior knowledge of computer programming is needed.

Prerequisite(s): ((AS.110.106 AND AS.110.107) OR (AS.110.108 AND AS.110.109) OR (AS.110.107 AND AS.110.108) OR (AS.110.106 OR AS.110.109)) AND (AS.030.103 OR (AS.030.101 AND AS.030.102)) AND ((AS.171.101 OR AS.171.103 OR AS.171.107) AND (AS.171.102 OR AS.171.104 OR AS.171.108));EN.500.113

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.312. Thermodynamics/Materials. 3 Credits.

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. This course contains computational modules; some prior knowledge of computer programming is needed.

Prerequisite(s): EN.510.311 AND EN.500.113

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.313. Mechanical Properties of Materials. 3 Credits.

An introduction to the properties and behavior of materials subjected to mechanical forces and deformation. Topics include the influence of composition and microstructure on the stiffness, strength, and toughness of materials. Particular emphasis is placed on fundamental mechanisms of deformation and fracture in the basic classes of materials (metals, ceramics, and polymers) as well as more complex materials (composites and biomaterials).

Prerequisite(s): EN.500.113 AND EN.510.312;EN.510.311 can be taken prior to enrolling in or at the same time as EN.510.313.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.314. Electronic Properties of Materials. 3 Credits.

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 conductivity and mobility, thermoelectricity, dielectric effects, piezoelectricity, photonic transmission and energetics, and magnetic phenomena. Mechanical force-based, quantum, and chemical explanations are presented and commonalities among them developed. Contemporary topics relevant to technology, sustainability, and medicine are explored.

Prerequisite(s): EN.510.311 AND EN.510.312

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.315. Physical Chemistry of Materials II. 3 Credits.

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 multi-component systems, solidification, diffusional and diffusionless transformations, and interfacial phenomena. This course contains computational modules; some prior knowledge of computer programming is needed.

Prerequisite(s): EN.510.311 AND EN.510.312

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.316. Foundations of Biomaterials. 3 Credits.

As one of the six courses in the Introduction to Materials Science series, this course offers an overview of principles and properties of polymeric and soft materials for biomedical applications. Topics include synthesis and structure-property relationship of polymeric materials, natural and biomimetic materials, biodegradable materials, hydrogels and stimuli-sensitive materials, surface property and characterizations of biomaterials. Recommended Course Background: Introductory Organic Chemistry I (AS.030.205 or the equivalent).

Prerequisite(s): ((AS.110.106 AND AS.110.107) OR (AS.110.108 AND AS.110.109) OR (AS.110.107 AND AS.110.108) OR (AS.110.106 AND AS.110.109)) AND (AS.030.103 OR(AS.030.101 AND AS.030.102)) AND ((AS.171.101 OR AS.171.103 OR AS.171.107) AND (AS.171.102 OR AS.171.104 OR AS.171.108)) AND AS.030.205

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.335. MSE Design Team I. 3 Credits.

This course is the first half of a two-semester course sequence for freshmen, sophomores, and juniors majoring or double majoring in materials science and engineering (MSE). This course provides a broad exposure to various aspects of planning and conducting independent research in a team setting (3 to 6 students on each team). In this course, MSE freshmen, sophomores, and juniors, working with a team leader and seniors on the team, apply their general knowledge in MSE to develop the solution to open-ended problems. *The team will meet 150 minutes per week at a time to be designated by the instructor. Recommended Course Background: EN.510.101, EN.510.109, or equivalent courses.

Distribution Area: Engineering, Natural Sciences

EN.510.336. MSE Design Team II. 3 Credits.

This course is the second half of a two-semester course sequence for juniors majoring or double majoring in materials science and engineering (MSE). This course provides a broad exposure to various aspects of planning and conducting independent research in a team setting (3 to 6 students on each team). In this course, MSE juniors working with a team leader and seniors on the team, apply their general knowledge in MSE to develop the solution to open-ended problems. Materials Science & Engineering Freshman Only. Recommended Course Background: EN.510.106, EN.510.109, or equivalent courses. *The team will meet 150 minutes per week at a time to be designated by the instructor.

Prerequisite(s): EN.510.335

Distribution Area: Engineering, Natural Sciences

EN.510.400. Introduction to Ceramics. 3 Credits.

This course will examine the fundamental structure and property relationships in ceramic materials. Areas to be studied include the chemistry and structure of ceramics and glasses, microstructure and property relationships, ceramic phase relationships, and ceramic properties. Particular emphasis will be placed on the physical chemistry of particulate systems, characterization, and the surface of colloid chemistry of ceramics. Recommended Course Background: EN.510.311, EN.510.312, or permission of instructor.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.402. Dynamics of Soft Materials. 3 Credits.

The structure and properties of soft materials will be studied with the focus on understanding ways to control and measure the dynamics. Soft materials to be studied include colloids, emulsions, dispersions, drops, polymers and gels. We will use experimental tools to study these materials including optical microscopy, rheometers, and atomic force microscopy. Recommended Course Background: EN.510.311 or permission of instructor.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.407. Biomaterials Principles and Applications. 3 Credits.

This course focuses on the interaction of biomaterials with the biological system and applications of biomaterials. Topics include biomaterials fabrication and characterization, host reactions to biomaterials, cell-biomaterials interaction, biomaterials for tissue engineering applications, biomaterials for controlled drug and gene delivery, and biomaterials for artificial organs.

Prerequisite(s): EN.510.316 OR (AS.030.205 AND EN.580.221) or Permission of Instructor

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.414. Transmission electron microscopy: principle and practice. 3 Credits.

Introduction to basic principles of electron diffraction, phase contrast and Z-contrast and applications of these principles in microstructural characterization of materials by electron diffraction, high-resolution electron microscopy and scanning transmission electron microscopy. Also listed as EN.510.665.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.415. The Chemistry of Polymeric Materials Synthesis. 3 Credits.

Many of the latest breakthroughs in materials science and engineering have been driven by new approaches to their synthesis, which has allowed the preparation of materials with fanciful structures and fascinating properties. This advanced course will explore synthetic approaches to multifunctional and nanostructured polymeric materials, useful for application such as optics, electronics, energy conversion, tissue engineering, drug delivery, and parts fabrication. Participants will gain sufficient familiarity with synthesis options to be able to design research programs that rely on them. Emphasis will be placed the multiple approaches to synthesizing materials with repeated structures, including bond formation by step and chain growth methods, functional group attachments and distributions, and control of solid state structures. The latest developments from the current literature will be incorporated into class activities.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.419. Physical Metallurgy. 3 Credits.

Fundamentals of metals and modern alloy systems, emphasizing the development and stability of microstructure and the physical basis linking microstructure to mechanical properties. Topics include thermodynamics of alloy systems, solidification, phase transformations, mechanisms of deformation and fracture, and alloy design. Examples will be drawn from a variety of systems including ferrous alloys (steels), lightweight alloys (aluminum and magnesium), alloys for high temperature applications (superalloys), and recent developments including metallic glasses and high-entropy alloys.

Prerequisite(s): EN.510.311 AND EN.510.313 AND EN.510.315

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.420. Stealth Science & Engineering. 3 Credits.

The goal of stealth engineering is the creation of objects that are not easily detected using remote sensing techniques. To achieve this end, engineered systems of materials are arrayed to alter the signature of objects by reducing energy returned to remote observers. This course will provide an introduction to the general principles behind signature reduction by examining the mathematics and science behind basic electromagnetic and acoustic transport processes. Specific topics will include energy absorbing materials, anti-reflection coatings, wave guiding and scattering, metamaterials and adaptive screens. Co-listed with EN.510.640

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.422. Micro and Nano Structured Materials & Devices. 3 Credits.

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.

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.425. Advanced Materials for Battery. 3 Credits.

This class provides an overview of the basic principles of electrochemical energy storage and the essential roles of advanced materials in batteries. Materials selection and design for the anodes and cathodes of lithium and sodium batteries are introduced on the basis of crystallography and materials chemistry. State-of-the-art operando characterization techniques of battery materials are also discussed in the course. This course is also listed as EN.510.625.

Prerequisite(s): EN.510.311 AND EN.510.312

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.426. Biomolecular Materials I - Soluble Proteins and Amphiphiles. 3 Credits.

This course will examine the fundamental structure, interactions, and function relationship for biological macromolecules. The course will emphasize experimental methods and experimental design, and the physics behind human disease. Topics will include micellization, protein folding and misfolding, and macromolecular interactions. Required Course Pre-Requisites: EN.580.221 & EN.510.312 - Co-listed with EN.510.621

Prerequisite(s): EN.580.221 AND EN.510.312

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.428. Materials Science Laboratory I. 3 Credits.

This course focuses on characterizing the microstructure and mechanical properties of structural materials that are commonly used in modern technology. A group of Al 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. Restricted to Materials Science & Engineering juniors only

Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;EN.510.311;EN.510.313 may be taken prior to enrolling in, or at the same time as, EN.510.428

Corequisite(s): EN.510.315 AND EN.510.313 must be taken at the same time as EN.510.428.

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)
Writing Intensive

EN.510.429. Materials Science Laboratory II. 3 Credits.

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. Lab Assignment is by Professor. Recommended Course Background: EN.510.311 or Permission Required.

Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.;EN.510.311;EN.510.313 can be taken prior to enrolling, or at the same time as, EN.510.429.

Corequisite(s): EN.510.314 must be taken at the same time as EN.510.429.

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)
Writing Intensive

EN.510.430. Biomaterials Lab. 3 Credits.

This laboratory course focuses on the synthesis, characterization, and application of biomaterials in cellular and biomedical research. The class covers a broad range of scenarios where biomaterials play vital roles, including cell culture, gene delivery, tissue modeling, and cell sensing. Students will also learn the basic lab techniques in biomedical research, including cell and tissue cultures, heterologous gene expression, and cell imaging. Recommended Course Background: EN.510.407

Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module.

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)
Writing Intensive

EN.510.433. Senior Design Research. 3 Credits.

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 pre-proposals (white papers), proposals, status reports and lecture critiques of the weekly departmental research seminar. Co-listed with EN.510.438 and EN.510.440

Prerequisite(s): (EN.510.311 AND EN.510.312 AND EN.510.313 AND EN.510.314 AND EN.510.315 EN.510.316) AND (EN.510.428 AND EN.510.429)

Distribution Area: Engineering
AS Foundational Abilities: Science and Data (FA2)
Writing Intensive

EN.510.434. Senior Design/Research II. 3 Credits.

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. Recommended Course Background: EN.510.311-EN.510.312, EN.510.428-EN.510.429, and EN.510.433 Meets with EN.510.439, EN.510.441, EN.510.446, and EN.510.448

Prerequisite(s): EN.510.433

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)
Writing Intensive

EN.510.436. Biomaterials for Cell Engineering. 3 Credits.

This course focuses on the development of biomaterials both as new tools to study fundamental biology and as means to direct cell behavior and function for biomedical applications. Topics include the material properties of cells and tissue, biomaterials for recapitulating cell microenvironment, biomaterials for studying and directing cell mechanotransduction, biomaterials for gene editing, biomaterials for immunotherapy, and biomaterials for neuroengineering. This course will have in-depth discussions on recent findings and publications in these areas. This course is also listed as EN.510.636.

Prerequisite(s): (EN.510.316 OR EN.510.407 OR EN.510.610

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)

EN.510.438. Biomaterials Senior Design I. 3 Credits.

This course is the first half of a two-semester sequence required for seniors majoring in materials science and engineering with the Biomaterials Concentration. It is intended to provide a broad exposure to many aspects of planning and conducting independent research with a focus on biomaterials. During this semester, students join ongoing graduate research projects for a typical 10-12 hours per week of hands-on experiences in design and research. Classroom activities include discussions, followed by writing of research pre-proposals (white papers), proposals, status reports and lecture critiques of departmental research seminars. Co-listed with EN.510.440 and EN.510.433

Prerequisite(s): EN.510.311 AND EN.510.312 AND EN.510.313 AND EN.510.314 AND EN.510.315 AND EN.510.316 AND EN.510.428 AND EN.510.429

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)
Writing Intensive

EN.510.439. Biomaterials Senior Design II. 3 Credits.

This course is the second half of a two-semester sequence required for seniors majoring in materials science and engineering with the Biomaterials Concentration. It is intended to provide a broad exposure to many aspects of planning and conducting independent research with a focus on biomaterials. 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 poster and a written final report summarizing their design and research results. Recommended Course Background: EN.510.311-EN.510.312, EN.510.428-EN.510.429, and EN.510.433 or 510.438 or 510.440 Meets with EN.510.434, EN.510.441, EN.510.446, and EN.510.448

Prerequisite(s): EN.510.311 AND EN.510.312 AND EN.510.313 AND EN.510.314 AND EN.510.315 AND EN.510.316 AND EN.510.428 AND EN.510.429

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)
Writing Intensive

EN.510.440. Nanomaterials Senior Design I. 3 Credits.

This course is the first half of a two-semester sequence required for seniors majoring in materials science and engineering with the Nanotechnology Concentration. It is intended to provide a broad exposure to many aspects of planning and conducting independent research with a focus on nanotechnology and nanomaterials. During this semester, students join ongoing graduate research projects for a typical 10-12 hours per week of hands-on experiences in design and research. Classroom activities include discussions, followed by writing of research pre-proposals (white papers), proposals, status reports and lecture critiques of departmental research seminars. Co-listed with EN.510.433 and EN.510.438

Prerequisite(s): (EN.510.311 AND EN.510.312 AND EN.510.313 AND EN.510.314 AND EN.510.315 AND EN.510.316) AND (EN.510.428 AND EN.510.429)

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)
Writing Intensive

EN.510.441. Nanomaterials Senior Design II. 3 Credits.

This course is the second half of a two-semester sequence required for seniors majoring in materials science and engineering with the Nanotechnology Concentration. It is intended to provide a broad exposure to many aspects of planning and conducting independent research with a focus on nanotechnology and nanomaterials. 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 poster and a written final report summarizing their design and research results. Recommended Course Background: EN.510.311-EN.510.312, EN.510.428-EN.510.429, and EN.510.433 or 510.438 or 510.440 Meets with EN.510.434, EN.510.439, EN.510.446, and EN.510.448

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)
Writing Intensive

EN.510.442. Nanomaterials Lab. 3 Credits.

The objective of the laboratory course will be to give students hands on experience in nanotechnology based device fabrication through synthesis, patterning, and characterization of nanoscale materials. The students will use the knowledge gained from the specific synthesis, characterization and patterning labs to design and fabricate a working nanoscale/nanostructured device. The course will be augmented with comparisons to microscale materials and technologies. These comparisons will be key in understanding the unique phenomena that enable novel applications at the nanoscale. DMSE Seniors or permission of the instructor.

Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class. To access the tutorial, login to myLearning and enter 458083 in the Search box to locate the appropriate module. Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)

EN.510.443. Chemistry and Physics of Polymers. 3 Credits.

The course will describe and evaluate the synthetic routes, including condensation and addition polymerization, to macromolecules with varied constituents and properties. Factors that affect the efficiencies of the syntheses will be discussed. Properties of polymers that lead to technological applications will be covered, and the physical basis for these properties will be derived. Connections to mechanical, electronic, photonic, and biological applications will be made. Also listed as EN.510.643. Recommended Course Background: Organic Chemistry I and one semester of thermodynamics.

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)

EN.510.445. MSE Design Team II. 3 Credits.

This course is the first half of a two-semester course sequence for senior students majoring or double majoring in MSE. This course provides a broad experience to various aspects of planning and conducting independent research in a team setting (3 to 6 students on each team). In this course, MSE seniors, working with a team leader and a group of freshmen, sophomores, and seniors, apply their knowledge in their track area to generate the solution to open-ended problems encountered in MSE. Recommended Course Background: EN.510.101, EN.510.311, EN.510.312, EN.510.428, EN.510.429.

Prerequisite(s): EN.510.311 AND EN.510.312 AND EN.510.313 AND EN.510.314 AND EN.510.315 AND EN.510.316 AND EN.510.428 AND EN.510.429

Distribution Area: Engineering, Natural Sciences
Writing Intensive

EN.510.446. MSE Design Team II. 3 Credits.

This course is the second half of a two-semester course sequence for senior students majoring or double majoring in MSE. This course provides a broad experience to various aspects of planning and conducting independent research in a team setting (3 to 6 students on each team). In this course, MSE seniors, working with a team leader and a group of freshmen, sophomores, and seniors, apply their knowledge in their track area to generate the solution to open-ended problems encountered in MSE. Materials Science & Engineering Seniors Only. Recommended Course Background: EN.510.101, EN.510.311, EN.510.312, EN.510.428, EN.510.429. Meets with EN.510.434, EN.510.439, EN.510.441 and EN.510.448.

Prerequisite(s): EN.510.445; EN.510.311 AND EN.510.312 AND EN.510.313 AND EN.510.314 AND EN.510.315 AND EN.510.316 AND EN.510.428 AND EN.510.429

Distribution Area: Engineering, Natural Sciences

EN.510.447. MSE Design Team Leader. 4 Credits.

This course is the first half of a two-semester course sequence for students majoring or double majoring in MSE. This course provides a leadership experience to various aspects of planning and conducting independent research in a team setting. In this course, MSE seniors assemble and lead a student team consisting of 3 to 6 students, apply their knowledge in their track area, and develop leadership skills to generate the solution to open-ended problems encountered in MSE. Recommended Course Background: EN.510.101, EN.510.311, EN.510.312, EN.510.428, EN.510.429.

Distribution Area: Engineering, Natural Sciences
Writing Intensive

EN.510.448. MSE Design Team Leader. 4 Credits.

This course is the second half of a two-semester course sequence for students majoring or double majoring in MSE. This course provides a leadership experience to various aspects of planning and conducting independent research in a team setting. In this course, MSE seniors assemble and lead a student team consisting of 3 to 6 students, apply their knowledge in their track area, and develop leadership skills to generate the solution to open-ended problems encountered in MSE. Materials Science & Engineering Seniors Only. Recommended Course Background: EN.510.101, EN.510.311, EN.510.312, EN.510.428, EN.510.429. Meets with EN.510.434, EN.510.439, EN.510.441, and EN.510.446

Prerequisite(s): EN.510.447

Distribution Area: Engineering, Natural Sciences

EN.510.451. Recycling for Sustainability. 3 Credits.

"I'm so confused...which bin do I choose?" Recycling everyday materials and re-using objects made from them have been part of our country's materials-usage landscape for decades. However, as we engineer a sustainable future, recycling will become an ever-increasing component of our strategies for material selection and product design. This course provides an overview of recycling – from the basics of materials recovery, processing and re-use to its economic and environmental impacts. Students will learn about industrial practices associated with recycling and how these relate to our everyday consumer behaviors. Field experiences and laboratory demonstrations will expose students to the realities of recycling. The challenges associated with recycling will be examined to gain a greater understanding of issues related to the use of materials in a sustainable world.

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)

EN.510.452. Materials in Extreme Environments. 3 Credits.

This survey course provides a broad perspective of the challenges materials face in evolving technologies related to energy production, aerospace, medicine, and even data storage. The course will introduce topics by technology and review the current materials in use, the challenges they face, and the future outlook in terms of opportunities, improvements, and research. Information will be provided from literature, media, and guest speakers from key industries and technology sectors.

EN.510.453. Materials Characterization. 3 Credits.

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 thermal analysis and surface analytical techniques, including Auger electron spectroscopy, secondary ion mass spectroscopy, X-ray photoelectron spectroscopy, and atomic force microscopy. Working with the JHU museums, we will use the techniques learned in class to characterize historic artifacts.

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)

EN.510.454. Nanomaterials for Genetic Medicine. 3 Credits.

This course describes how nanomaterials have facilitated and will advance genetic medicine in clinical applications for disease treatment and prevention. Topics of this course include synthesis and structure-activity relationship of hard and soft nanoparticles, biomimetic nanomaterials, nanomaterials for nucleic acid delivery, nanomaterials for genome editor delivery, biological fate of nanomaterials, and nano-bio interface characterization. This course will have in-depth discussions on recent progress and publications in these areas.

EN.510.456. Computational modeling of soft/bio materials. 3 Credits.

This course provides an overview of computational modeling methods with practical applications for designing soft materials and biomaterials. Computational methods include Monte Carlo, molecular dynamics, Bayesian analysis, machine learning, and the basics of finite-element modeling. The course is part project-based and teaches both the fundamentals of computational methods and how to apply them to current cutting-edge research in soft and biomaterials.

Prerequisite(s): Students who have taken or are enrolled in EN.510.656 are not eligible to take EN.510.456.; EN.500.113 AND EN.510.312

EN.510.457. Materials Science of Thin Films. 3 Credits.

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. Co-listed with EN.510.657

Distribution Area: Engineering, Natural Sciences
AS Foundational Abilities: Science and Data (FA2)

EN.510.466. Introduction to Computational Materials Modeling. 3 Credits.

Moore's law has given rise to the silicon age, where computational modeling can provide high-fidelity predictions to address challenges spanning climate change and renewable energy to economic stability and global pandemics. The skills to solve scientific problems computationally have become invaluable in virtually all industries. This introductory course is project-based and puts into practice the fundamentals of software development, numerical analysis, and scientific programming. Topics covered include methods for solving differential equations, Monte Carlo and atomistic simulations, machine learning, and data visualization. The course is taught in Python, and support for non-UNIX architectures is limited.

Prerequisite(s): EN.500.113 AND EN.510.311 AND EN.510.312

EN.510.467. Metal Additive Manufacturing. 3 Credits.

Additive Manufacturing (AM), also known colloquially as 3D Printing, is a disruptive technology that has received significant attention in recent years in both the popular press and the manufacturing industry. While the current and potential future applications for this technology, especially for mission-critical metal parts, are impressive and imaginative, the full potential for metal AM has not been realized due to current limitations and a lack of full understanding of metal AM processes. In this class we will cover (1) the current state-of-the-art of AM; (2) the production steps necessary to manufacture AM parts; and (3) the closely linked topics of AM materials and AM processes. While non-metal AM materials such as polymers, composites, and ceramics will be included, the primary focus will be on metal materials fabricated with laser powder bed fusion processes. Specific topics covered will include conventional vs. AM materials, meltpool phenomena including solidification, kinetics and solid-state kinetics, post-process thermal treatments, the process-properties relationship, in-situ process sensing, indirect process measurement methods and process modeling. Recent implementations of metal additive manufacturing, such as those in the aerospace and health care industries, will be presented extensively throughout the class as study cases. Popular press articles and technical papers on AM will be reviewed and discussed. Students taking this class will be expected to participate actively and bring to the class real or potential applications of AM in their workplaces. Co-listed with EN.510.667

Prerequisite(s): EN.510.311 AND EN.510.315

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.510.501. Undergraduate Research in Material Science. 3 Credits.

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.

Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class.; You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration, Online Forms.

EN.510.502. Research in Materials Science. 1 - 3 Credits.

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.

Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration, Online Forms.

EN.510.504. Independent Study. 1 - 3 Credits.

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(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration, Online Forms.

EN.510.511. Group Undergraduate Research/Material Science. 3 Credits.

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. This section has a weekly research group meeting that students are expected to attend.

Prerequisite(s): Students must have completed Lab Safety training prior to registering for this class.; You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration, Online Forms.

EN.510.597. Research - Summer. 3 Credits.

Undergraduates who want to do Independent Academic Work with a department faculty member in the summer must use the Independent Academic Work form found in Student Self-Service: Registration Online Forms.

Prerequisite(s): You must request Independent Academic Work using the Independent Academic Work form found in Student Self-Service: Registration, Online Forms.

EN.510.601. Structure Of Materials. 3 Credits.

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. Recommended Course Background: undergraduate chemistry, physics, and calculus or permission of instructor.

EN.510.602. Thermodynamics Of Materials. 3 Credits.

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. Recommended Course Background: undergraduate calculus, chemistry, and physics or permission of instructor.

EN.510.603. Phase Transformations of Materials. 3 Credits.

A detailed study of kinetic processes in materials is used to understand processing and microstructural evolution of materials. Topics include chemical rate equations, diffusion (equilibrium and non-equilibrium), interface thermodynamics, nucleation, solidification and crystal growth, phase transformations, and coarsening.

EN.510.604. Mechanical Properties of Materials. 3 Credits.

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. Recommended Course Background: EN.510.601

Prerequisite(s): Students who have taken EN.530.604 are not eligible to take EN.510.604.

EN.510.605. Electrical, Optical and Magnetic Properties of Materials. 3 Credits.

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. Emphasis will be placed on both fundamental principles and applications in contemporary materials technologies. Recommended Course Background: EN.510.601

EN.510.610. Fundamentals of Biomaterials. 3 Credits.

This course provides an introduction to biomaterials in medicine. Topics include: hard and soft biomaterials, materials science concepts specific to biomaterials, surface thermodynamics, surfactants and surface functionalization, proteins and protein-surface interactions, tissue engineering and regenerative medicine, wound healing and the inflammatory response, and drug delivery systems. Pre-requisites: 510.602 (Thermodynamics of Materials) or permission of instructor. No Audits.

Distribution Area: Engineering, Natural Sciences

EN.510.615. Physical Properties of Materials. 3 Credits.

A detailed survey of the relationship between materials properties and underlying microstructure. Structure/property/processing relationships will be examined across a wide spectrum of materials including metals, ceramics, polymers and biomaterials, and properties including electrical, magnetic, optical, thermal, mechanical, chemical and biocompatibility. Distribution Area: Engineering, Natural Sciences

EN.510.619. Physical Metallurgy. 3 Credits.

Fundamentals of metals and modern alloy systems, emphasizing the development and stability of microstructure and the physical basis linking microstructure to mechanical properties. Topics include thermodynamics of alloy systems, solidification, phase transformations, mechanisms of deformation and fracture, and alloy design. Examples will be drawn from a variety of systems including ferrous alloys (steels), lightweight alloys (aluminum and magnesium), alloys for high temperature applications (superalloys), and recent developments including metallic glasses and high-entropy alloys.

Prerequisite(s): EN.510.601 AND EN.510.602; EN.510.603 AND (EN.510.604 OR EN.530.604)

Distribution Area: Engineering, Natural Sciences

EN.510.621. Biomolecular Materials I - Soluble Proteins and Amphiphiles. 3 Credits.

Structure and function of cellular molecules (lipids, nucleic acids, proteins, and carbohydrates). Structure and function of molecular machines (enzymes for biosynthesis, motors, pumps). Protein synthesis using recombinant nucleic acid methods. Advanced materials development. Interactions of biopolymers, lipid membranes, and their complexes. Mean field theories, fluctuation and correlation effects. Self assembly in biomolecular materials. Biomedical applications. Characterization techniques. Structure and function of cellular molecules (lipids, nucleic acids, proteins, and carbohydrates). Structure and function of molecular machines (enzymes for biosynthesis, motors, pumps). Protein synthesis using recombinant nucleic acid methods. Advanced materials development. Interactions of biopolymers, lipid membranes, and their complexes. Mean field theories, fluctuation and correlation effects. Self assembly in biomolecular materials. Biomedical applications. Characterization techniques. Co-listed with EN.510.426.

Distribution Area: Engineering, Natural Sciences

EN.510.622. Micro and Nano Structured Materials & Devices. 3 Credits.

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 510.622/422)

EN.510.624. X-ray Scattering, Diffraction, and Imaging. 3 Credits.

An introduction to the uses of x-rays for structural characterization of materials, including (i) kinematic theory of x-ray scattering and diffraction by single crystals, polycrystals, liquids, and amorphous solids; (ii) principles of Fourier optics with applications to x-ray radiography and phase-contrast x-ray imaging; and (iii) x-ray computed tomography (CT). Prerequisite: 510.601 or equivalent.

EN.510.625. Materials Science Fundamentals for Batteries. 3 Credits.

This course is designed to provide a comprehensive understanding of the principles underlying the development and operation of solid-state batteries, including the current state of the energy storage landscape. The course will delve into thermodynamics, kinetics, materials selection involved in solid-state battery design, interfacial electrochemistry, experimental methods, and practical considerations. Overall, this course is ideal for individuals interested in the emerging field of solid-state batteries and their potential applications.

Prerequisite(s): EN.510.601 AND EN.510.602

EN.510.630. Molecular Simulation of Materials. 3 Credits.

Learn the fundamentals necessary to design and implement computer simulations on the molecular level. This course focuses on two widely used techniques: molecular-dynamics and Monte Carlo simulation. Both are introduced in the context of a review of the basic theoretical background. This class will cover the specifics of handling molecular interactions using empirical potentials, applying proper boundary conditions and simulating various equilibrium ensembles and non-equilibrium systems. Lectures will address how to extract transport coefficients, atomic scale correlations and local stresses and strains from simulation data, and computational issues such as algorithmic complexity and efficiency. The final weeks of the course will focus on new and cutting-edge advances in these methods.

Distribution Area: Engineering, Natural Sciences

EN.510.636. Biomaterials for Cell Engineering. 3 Credits.

This course focuses on the development of biomaterials both as new tools to study fundamental biology and as means to direct cell behavior and function for biomedical applications. Topics include the material properties of cells and tissue, biomaterials for recapitulating cell microenvironment, biomaterials for studying and directing cell mechanotransduction, biomaterials for gene editing, biomaterials for immunotherapy, and biomaterials for neuroengineering. This course will have in-depth discussions on recent findings and publications in these areas. This course is also listed as EN.510.436.

EN.510.640. Stealth Engineering. 3 Credits.

The goal of stealth engineering is the creation of objects that are not easily detected using remote sensing techniques. To achieve this end, engineered systems of materials are arrayed to alter the signature of objects by reducing energy returned to remote observers. This course will provide an introduction to the general principles behind signature reduction by examining the mathematics and science behind basic electromagnetic and acoustic transport processes. Specific topics will include energy absorbing materials, anti-reflection coatings, wave guiding and scattering, metamaterials and adaptive screens. Co-listed with EN.510.420.

Distribution Area: Engineering, Natural Sciences

EN.510.643. Chemistry and Physics of Polymers. 3 Credits.

The course will describe and evaluate the synthetic routes, including condensation and addition polymerization, to macromolecules with varied constituents and properties. Factors that affect the efficiencies of the syntheses will be discussed. Properties of polymers that lead to technological applications will be covered, and the physical basis for these properties will be derived. Connections to mechanical, electronic, photonic, and biological applications will be made. Also listed as EN.510.443. Recommended Course Background: Organic Chemistry I and one semester of thermodynamics.

Distribution Area: Engineering, Natural Sciences

EN.510.652. Materials in Extreme Environments. 3 Credits.

This survey course provides a broad perspective of the challenges materials face in evolving technologies related to energy production, aerospace, medicine, and even data storage. The course will introduce topics by technology and review the current materials in use, the challenges they face, and the future outlook in terms of opportunities, improvements, and research. Information will be provided from literature, media, and guest speakers from key industries and technology sectors.

EN.510.653. Materials Characterization. 3 Credits.

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 thermal analysis and surface analytical techniques, including Auger electron spectroscopy, secondary ion mass spectroscopy, X-ray photoelectron spectroscopy, and atomic force microscopy. Working with the JHU museums, we will use the techniques learned in class to characterize historic artifacts.

EN.510.654. Nanomaterials for Genetic Medicine. 3 Credits.

This course describes how nanomaterials have facilitated and will advance genetic medicine in clinical applications for disease treatment and prevention. Topics of this course include synthesis and structure-activity relationship of hard and soft nanoparticles, biomimetic nanomaterials, nanomaterials for nucleic acid delivery, nanomaterials for genome editor delivery, biological fate of nanomaterials, and nano-bio interface characterization. This course will have in-depth discussions on recent progress and publications in these areas.

EN.510.656. Computational modeling of soft/bio materials. 3 Credits.

This course provides an overview of computational modeling methods with practical applications for designing soft materials and biomaterials. Computational methods include Monte Carlo, molecular dynamics, Bayesian analysis, machine learning, and the basics of finite-element modeling. The course is part project-based and teaches both the fundamentals of computational methods and how to apply them to current cutting-edge research in soft and biomaterials.

Prerequisite(s): Students who are enrolled in or have taken EN.510.456 are not eligible to take EN.510.656.

EN.510.657. Materials Science of Thin Films. 3 Credits.

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. Co-listed with EN.510.457

EN.510.658. Electroanalytical Chemistry & Energy Conversion. 3 Credits.

Electrochemical methods are used by researchers in many fields to study topics such as (photo)electrocatalysis, batteries, and chemical sensors. This course will cover the basic theory and applications of electrochemistry to provide students with foundational knowledge of electrified solid-solution interfaces. Fundamental topics including interfacial charge transfer, mass transport, electric double layer structure, electrode kinetics, and analytical methods will be covered. State-of-the-art topics in electrochemistry research will also be discussed.

Distribution Area: Engineering

EN.510.662. Transmission Electron Microscopy: Methods. 3 Credits.

Transmission Electron Microscopy Methods is a hands-on, lab-based course design to give graduate students practical working knowledge of TEM methods. The course includes weekly 3 hr labs where students, in groups of four, will be instructed in the basic techniques needed to perform their characterization requirements of their research. In each lab students will learn a technique with which they will apply to a material and produce a report. Reports will be a transcription of steps taken in lab, documentation of data including images, spectra, measurements, and interpretation of data. At the end of the course, each group will produce a characterization report of a material of their choice.

EN.510.665. Transmission electron microscopy: principle and practice. 3 Credits.

Introduction to basic principles of electron diffraction, phase contrast and Z-contrast and applications of these principles in microstructural characterization of materials by electron diffraction, high-resolution electron microscopy and scanning transmission electron microscopy. Also listed as EN.510.414.

Distribution Area: Engineering, Natural Sciences

EN.510.666. Introduction to Computational Materials Modeling. 3 Credits.

Moore's law has given rise to the silicon age, where computational modeling can provide high-fidelity predictions to address challenges spanning climate change and renewable energy to economic stability and global pandemics. The skills to solve scientific problems computationally have become invaluable in virtually all industries. This introductory course is project-based and puts into practice the fundamentals of software development, numerical analysis, and scientific programming. Topics covered include methods for solving differential equations, Monte Carlo and atomistic simulations, machine learning, and data visualization. The course is taught in Python, and support for non-UNIX architectures is limited.

EN.510.667. Metal Additive Manufacturing. 3 Credits.

Additive Manufacturing (AM), also known colloquially as 3D Printing, is a disruptive technology that has received significant attention in recent years in both the popular press and the manufacturing industry. While the current and potential future applications for this technology, especially for mission-critical metal parts, are impressive and imaginative, the full potential for metal AM has not been realized due to current limitations and a lack of full understanding of metal AM processes. In this class we will cover (1) the current state-of-the-art of AM; (2) the production steps necessary to manufacture AM parts; and (3) the closely linked topics of AM materials and AM processes. While non-metal AM materials such as polymers, composites, and ceramics will be included, the primary focus will be on metal materials fabricated with laser powder bed fusion processes. Specific topics covered will include conventional vs. AM materials, meltpool phenomena including solidification, kinetics and solid-state kinetics, post-process thermal treatments, the process-properties relationship, in-situ process sensing, indirect process measurement methods and process modeling. Recent implementations of metal additive manufacturing, such as those in the aerospace and health care industries, will be presented extensively throughout the class as study cases. Popular press articles and technical papers on AM will be reviewed and discussed. Students taking this class will be expected to participate actively and bring to the class real or potential applications of AM in their workplaces. Co-listed with EN.510.467

Prerequisite(s): EN.510.601

Distribution Area: Engineering, Natural Sciences

EN.510.801. Materials Research Seminar. 1 Credit.

The Graduate Research Seminar in the Department of Materials Science and Engineering provides a forum for students to present their latest research results in a formal seminar setting. The course encourages discussion between students in varying disciplines in order to establish new collaborations and develop the shared vocabulary required for interdisciplinary materials science research. Permission Required.

EN.510.802. Materials Research Seminar. 1 Credit.

The Graduate Research Seminar in the Department of Materials Science and Engineering provides a forum for students to present their latest research results in a formal seminar setting. The course encourages discussion between students in varying disciplines to establish new collaborations and develop the shared vocabulary required for interdisciplinary materials science research. Permission Required.

EN.510.803. Materials Science Seminar. 1 Credit.

The Materials Science Seminar exposes students to a wide array of internationally recognized speakers who discuss topics of cutting-edge Materials Science research. Speakers are selected both to overlap research interests within the department and to expose students to broader trends in contemporary Materials Science.

EN.510.804. Materials Science Seminar. 1 Credit.

Meets with EN.510.434, EN.510.439, EN.510.441, EN.510.446, and EN.510.448.

EN.510.807. Graduate Research In Materials Science. 3 - 20 Credits.

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.

EN.510.808. Graduate Research. 3 - 20 Credits.

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.

EN.510.809. Graduate Summer Research Course. 9 Credits.

Graduate Summer Research Course

Cross Listed Courses**Biomedical Engineering****EN.580.441. Cellular Engineering. 3 Credits.**

This course focuses on principles and applications in cell engineering. Class lectures include an overview of molecular biology fundamentals, protein/ligand binding, receptor/ligand trafficking, cell-cell interactions, cell-matrix interactions, and cell adhesion and migration at both theoretical and experimental levels. Lectures will cover the effects of physical (e.g. shear stress, strain), chemical (e.g. cytokines, growth factors) and electrical stimuli on cell function, emphasizing topics on gene regulation and signal transduction processes. Furthermore, topics in metabolic engineering, enzyme evolution, polymeric biomaterials, and drug and gene delivery will be discussed. This course is intended as Part 1 of a two-semester sequence recommended for students in the Cell and Tissue Engineering focus area. Recommended Course Background: EN.580.221 or AS.020.305 and AS.020.306 or equivalent and AS.030.205 Meets with EN.580.641

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.580.442. Tissue Engineering. 3 Credits.

This course focuses on the application of engineering fundamentals to designing biological tissue substitutes. Concepts of tissue development, structure and function will be introduced. Students will learn to recognize the majority of histological tissue structures in the body and understand the basic building blocks of the tissue and clinical need for replacement. The engineering components required to develop tissue-engineered grafts will be explored including biomechanics and transport phenomena along with the use of biomaterials and bioreactors to regulate the cellular microenvironment. Emphasis will be placed on different sources of stem cells and their applications to tissue engineering. Clinical and regulatory perspectives will be discussed. Recommended Course Background:

EN.580.221 or AS.020.305 and AS.020.306, AS.030.205 Recommended EN.580.441/EN.580.641 Co-listed with EN.580.642

Distribution Area: Engineering, Natural Sciences

AS Foundational Abilities: Science and Data (FA2)

EN.580.444. Biomedical Applications of Glycoengineering. 3 Credits.

This course provides an overview of carbohydrate-based technologies in biotechnology and medicine. The course will begin by briefly covering basics of glycobiology and glycochemistry followed by detailed illustrative examples of biomedical applications of glycoengineering. A sample of these applications include the role of sugars in preventative medicine (e.g., for vaccine development and probiotics), tissue engineering (e.g., exploiting natural and engineered polysaccharides for creating tissue or organs de novo in the laboratory), regenerative medicine (e.g., for the treatment of arthritis or degenerative muscle disease), and therapy (e.g., cancer treatment). A major part of the course grade will be based on class participation with each student expected to provide a "journal club" presentation of a relevant paper as well as participate in a team-based project designed to address a current unmet clinical need that could be fulfilled through a glycoengineering approach. Recommended Course Background: EN.580.221 Molecules and Cells. Distribution Area: Engineering, Natural Sciences AS Foundational Abilities: Science and Data (FA2)

Electrical & Computer Engineering**EN.520.627. Photovoltaics and Energy Devices. 3 Credits.**

This course provides an introduction to the science of photovoltaics and related energy devices. Topics covered include basic concepts in semiconductor device operation and carrier statistics; recombination mechanisms; p-n junctions; silicon, thin film, and third generation photovoltaic technologies; light trapping; and detailed balance limits of efficiency. Additionally, thermophotovoltaics and electrical energy storage technologies are introduced. A background in semiconductor device physics (EN.520.485, or similar) is recommended.

General Engineering**EN.500.113. Gateway Computing: Python. 3 Credits.**

This course introduces fundamental programming concepts and techniques, and is intended for all who plan to develop computational artifacts or intelligently deploy computational tools in their studies and careers. Topics covered include the design and implementation of algorithms using variables, control structures, arrays, functions, files, testing, debugging, and structured program design. Elements of object-oriented programming, algorithmic efficiency and data visualization are also introduced. Students deploy programming to develop working solutions that address problems in engineering, science and other areas of contemporary interest that vary from section to section. Course homework involves significant programming. Attendance and participation in class sessions are expected.

Prerequisite(s): Students may only receive credit for one of the following courses: EN.500.112 OR EN.500.113 OR EN.500.114 OR EN.500.132 OR EN.500.133 OR EN.500.134

Distribution Area: Engineering

AS Foundational Abilities: Science and Data (FA2)

Mechanical Engineering**EN.530.436. Bioinspired Science and Technology. 3 Credits.**

Nature has been a source of inspiration for scientists and engineers and it receives particular attention recently to address many challenges the human society encounter. The course will study novel natural materials/structures with unique properties, the underlying principles, and the recent development of the bio-inspired materials and systems. From this course, students can learn about ingenious and sustainable strategies of organisms, open eyes about various phenomena in nature, and get inspiration for opening new directions of science and technology.

Distribution Area: Engineering, Natural Sciences

EN.530.445. Introduction to Biomechanics. 3 Credits.

An introduction to the mechanics of biological materials and systems. Both soft tissue such as muscle and hard tissue such as bone will be studied as will the way they interact in physiological functions. Special emphasis will be given to orthopedic biomechanics. Recommended Course Background: EN.530.215/EN.530.216 and Lab or equivalent. If you have not taken this course or an equivalent, please contact the instructor before registering to ensure you have the appropriate background knowledge to succeed in this course.

Distribution Area: Engineering

EN.530.604. Mechanical Properties of Materials. 3 Credits.

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. Recommended Course Background: EN.510.601

Prerequisite(s): Students who have taken EN.510.604 are not eligible to take EN.530.604.

EN.530.618. Fabricatology - Advanced Materials Processing. 3 Credits.

The "Fabricatology" is a course that students can learn how to make desired shapes, structures, and surfaces across various length scales. It will introduce rich scientific and engineering knowledge related to fabrication at multiple length scales and the generated materials and mechanical systems can be utilized for studying diverse topics including energy harvesting, metamaterials, wetting, and information storage. From this course, students can learn principles and technologies to control shapes at various length scales and processes to control internal structures or surface properties for desired properties/functions. They will be also introduced to exciting recent development in the field so that they can have a comprehensive knowledge about the subject. Recommended Course Background: coursework in introduction to materials chemistry or engineering materials.

For current faculty and contact information go to <http://materials.jhu.edu/index.php/people/>