Materials Science and Engineering

As science and technology advance in the 21st century, progress in many fields will depend on the discovery and development of new materials, processed in more complex ways, and with new kinds of properties. It is widely recognized that the progress of history has been divided into periods characterized by the materials that mankind has used, e.g., the stone age, the bronze age, the iron age. Today, materials science and engineering is critical to all other fields of engineering, and advances in other fields are often limited by advances in materials.

Interest in new materials for solid-state devices, space technology, and superconductivity, as well as a better understanding of the behavior of materials in the design of structures, automobiles and aircraft, plant processing equipment, electronic devices, biomedical devices, etc., have increased the need for people trained in science and technology of materials.

Education for this field of engineering requires basic studies in mathematics, chemistry, physics and mechanics, plus a general background in engineering principles, followed by intensive training in the application of these principles to the development and use of materials in a technological society.

Professors. Helen M. Chan, PhD (Imperial College London); Manoj K. Chaudhury, PhD (State University of New York at Buffalo); Xuanhong Cheng, PhD (University of Washington); Volkmar R. Dierolf, PhD (University of Utah); John N. DuPont, PhD (Lehigh University); Martin P. Harmer, DSc (University of Leeds); Himanshu Jain, EngScD (Columbia University); Christopher J. Kiely, PhD (University of Bristol); Wojciech Z. Misiolek, DSc (AGH University Science & Technology); Raymond A. Pearson, PhD (University of Michigan); Jeffrey M. Rickman, PhD (Carnegie Mellon University)

Associate Professors. Sabrina S. Jedlicka, PhD (Purdue University); Nicholas Strandwitz, PhD (University of California Santa Barbara); Masashi Watanabe, PhD (Kyushu University)

Assistant Professors. Joshua Carl Agar, PhD (University of Illinois at Urbana-Champaign); Lesley W. Chow, PhD (Northwestern University); Siddha Pimputkar, PhD (University of California, Santa Barbara)

Professor Of Practice. Eric S. Daniels, PhD (Lehigh University)

Emeriti. Betzalel Avitzur, PhD (University of Michigan); G. Slade Carmill, III, PhD (Harvard University); John Alwyn Eades, PhD (University of Cambridge); Richard W. Hertzberg, PhD (Lehigh University); Charles E. Lyman, PhD (Massachusetts Institute of Technology); Arnold R. Marder, PhD (Leigh University); Michael R Notis, PhD (Leigh University); Alan W. Pence, PhD (Leigh University); David A. Thomas, DSc (Massachusetts Institute of Technology); David B. Williams, PhD (University of Cambridge)

B.S. IN MATERIALS SCIENCE AND ENGINEERING

The undergraduate program is designed to prepare graduates for research, development, operations, management, and sales careers in industry or for graduate study in various specialties of the field, including the improvement of properties in metals, ceramics, polymers, composites, electronic materials, and biomaterials. While some graduates go directly into materials-producing companies, most serve as engineers in the transportation, electronics, chemical, communications, space, and other industries. A number of students pursue graduate study leading to careers in research and teaching, medicine, or the law.

Materials Science and Engineering majors have opportunities to gain valuable experience in related fields, including other areas of engineering or science, by choosing to concentrate elective courses in one of these areas. Requirements for the Minor include acquiring at least 15 course credits in that area, which may be taken as technical or free electives in the student's major. It is particularly straightforward for students to obtain a minor in Chemical and Biomolecular Engineering, in Mechanical Engineering, in Nanotechnology, or in Polymer Science and Engineering. There is also a path to a Business minor.

Materials Science and Engineering majors can also participate in undergraduate research at overseas universities during the summer between the Junior and Senior years. The Materials Science and Engineering Industrial Option program enables students to gain work experience during the Senior Year. The Materials Science and Engineering Research Option program provides senior undergraduates with research experience.

Five-Year programs are available to broaden the Materials Science and Engineering undergraduate experience. One such program is the Arts-Engineering Program, in which students can earn both the Bachelor of Science degree in Materials Science and Engineering and the Bachelor of Arts degree in some area within the College of Arts and Sciences, such as biology, physics, chemistry, or history. Another is the B.S./M.Ed. Program, which leads (in five years of study and internships) to the B.S. degree in Materials Science and Engineering and a masters degree (M.Ed.) in Education, with elementary or secondary teacher certification.

MINOR IN MATERIALS SCIENCE AND ENGINEERING

The Department of Materials Science and Engineering offers minors to students majoring in other subjects. The Department is enthusiastic in its support of students who wish to broaden their education by taking a minor. To obtain a minor in Materials Science and Engineering, a student must complete:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>MAT 033</td>
<td>Engineering Materials and Processes</td>
<td>3</td>
</tr>
<tr>
<td>MAT 10 or 028</td>
<td>may be used as an elective.</td>
<td>12</td>
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<tr>
<td>Total Credits</td>
<td></td>
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</table>

MINOR IN NANOTECHNOLOGY

Materials for nanotechnology applications have new properties unavailable in bulk materials. The synthesis, processing, and characterization of these materials require facility with concepts beyond those needed for typical engineering materials. This minor requires:

<table>
<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
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<tbody>
<tr>
<td>MAT 355</td>
<td>Materials for Nanotechnology</td>
<td>3</td>
</tr>
<tr>
<td>One course on crystallography and band theory</td>
<td>3</td>
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<tr>
<td>Additional electives</td>
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<tr>
<td>Total Credits</td>
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<td>15</td>
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</tbody>
</table>

Additional requirement: Since the aim of this minor is to provide an interdisciplinary program in nanotechnology, students must take at least one course outside their home department. Courses of individual study (including laboratory projects) on relevant topics, in any appropriate department, will also be accepted as electives for the minor, with the approval of the advisor.

EDUCATIONAL MISSION

The Materials Science and Engineering undergraduate program's mission is to pursue excellence and international prominence in the selection, design, synthesis, characterization, and discovery of materials at the nexus of experimental, computational, and data science techniques through distinguished research and scholarship, innovative teaching, industrial relationships, and active professional leadership. Our goal is to nurture and champion leaders who think critically, analytically, and broadly about grand challenges, both old and new, in an effort to improve the world around them.

PROGRAM EDUCATIONAL OBJECTIVES

- Graduates will have the knowledge and experience to pursue successful careers;
- Graduates will meet the expectations of employers;
- Qualified graduates will be admitted to highly ranked advanced degree programs; and
- Successful careers will be reflected in professional recognition, advancement in responsibility, and awards.
STUDENT OUTCOMES
The MS&E undergraduate Student Outcomes declare that graduates should have:
1. an ability to identify, formulate, and solve complex engineering problems by applying principles of engineering, science, and mathematics;
2. an ability to apply engineering design to produce solutions that meet specified needs with consideration of public health, safety, and welfare, as well as global, cultural, social, environmental, and economic factors;
3. an ability to communicate effectively with a range of audiences;
4. an ability to recognize ethical and professional responsibilities in engineering situations and make informed judgements, which must consider the impact of engineering solutions in global economic, environmental, and societal contexts;
5. an ability to function effectively on a team whose members together provide leadership, create a collaborative and inclusive environment, establish goals, plan tasks, and meet objectives;
6. an ability to develop and conduct appropriate experimentation, analyze and interpret data, and use engineering judgement to draw conclusions;
7. an ability to acquire and apply new knowledge as needed, using appropriate learning strategies.

MAJOR REQUIREMENTS
The recommended sequence of courses is shown below.

A total of 132 credits or more is required to graduate.

First Year

First Semester

<table>
<thead>
<tr>
<th>Course</th>
<th>Credits</th>
<th>Second Semester</th>
<th>Credits</th>
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<tr>
<td>ENGL 001</td>
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<td>ENGL 002</td>
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<td>MATH 021</td>
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<td>MATH 022</td>
<td>4</td>
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<tr>
<td>ENGR 005</td>
<td>2</td>
<td>PHY 011</td>
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<tr>
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<td>ECO 001</td>
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<td>Humanities or Social Sciences Elective</td>
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Second Year

First Semester

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<th>Course</th>
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<tr>
<td>MAT 033</td>
<td>2</td>
<td>MAT 203</td>
<td>4</td>
</tr>
<tr>
<td>MAT 010</td>
<td>2</td>
<td>MAT 205</td>
<td>3</td>
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<td>MATH 023</td>
<td>4</td>
<td>MAT 218</td>
<td>3</td>
</tr>
<tr>
<td>PHY 021</td>
<td>4</td>
<td>MAT 204</td>
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<td>PHY 022</td>
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Third Year

First Semester

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<td>MAT 206</td>
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<td>MAT 216</td>
<td>3</td>
<td>MAT 214</td>
<td>3</td>
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<tr>
<td>MAT 101</td>
<td>2</td>
<td>MAT 201</td>
<td>3</td>
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<tr>
<td>MATH 205</td>
<td>3</td>
<td>Engineering Science Elective</td>
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<tr>
<td>MECH 003</td>
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<td>Free Elective</td>
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Fourth Year

First Semester

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<tr>
<td>MAT 252</td>
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<td>MAT 268</td>
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<td>Engineering Science Elective</td>
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<td>Approved Elective</td>
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<td>MAT 212</td>
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<td>Free Elective</td>
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<td>15</td>
<td>17</td>
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</table>

Total Credits: 132

1. Required natural science courses, one taken fall semester and the other taken in spring
2. MAT 033 is taught in both the fall and spring semesters

PROGRAM REQUIREMENTS
Students must achieve a grade of C- or better in all required courses, in addition to a major GPA of 2.0.

ELECTIVES
Electives for the sophomore, junior, and senior years must be distributed as follows:

Humanities and Social Sciences: 13-15 credit hours.
Free Electives: 9 credit hours in any department.
Approved Elective (3 credit hours) and Engineering Science Electives (6 credit hours) must be selected from a specific list supplied by the Materials Science and Engineering Department. The list includes the Industrial Option and the Research Option.

PROGRAM OPTIONS
Recognizing that the field of materials science and engineering may be pursued in either an industrial setting or a research setting, the department offers three elective options to prepare students for these careers: The Co-Op Program, the Industrial Option, and the Research Option.

Co-Op Program
The department's optional Co-Op program, operated within the College of Engineering and Applied Science, provides opportunities for integration of academic studies with significant periods of engineering practice. The program provides eight months of paid, full-time work at selected companies, while still allowing the student to graduate in four years. To be considered for this program, the student should discuss application requirements with his or her advisor.

Industrial Option
MAT 327  Industrial Project  4
MAT 329  Industrial Project  4

Research Option
MAT 340  Research Techniques  3
MAT 341  Undergraduate research  3

Industrial Option
The Industrial Option introduces students to the work of materials engineers in industry. The emphasis is a team approach to the solution of actual plant problems. The courses are conducted in cooperation with local industries. 20 hours per week are spent at the plant of the cooperating industry on investigations of selected problems. The option is limited to a small group of seniors, selected by the Department from those who apply. Summer employment is provided when possible for those who elect to initiate the program during the summer preceding the senior year.
Research Option
The Research Option is offered for students interested in research and development. Financial support may be available for students who elect to initiate a research program during the summer preceding the senior year. The option is limited to a small group of students, selected by the Department from those who apply.

FOR GRADUATE STUDENTS
The department offers graduate degrees in Materials Science and Engineering at both masters (M.S. and M.Eng.) and doctoral levels (Ph.D.). Specialized masters degree programs are also available in Photonics, in Polymers, and in Business Administration and Engineering (MBA&E). The M.S. Degree in Photonics is an interdisciplinary degree for broad training in such topics as fiber optics, light-wave communications, and optical materials, to prepare students for work in industry or for further graduate research at the Ph.D. level. The program requires a total of 30 credits of graduate work, including a 15-credit core of courses in materials, electrical engineering, and physics. The Polymer Science and Engineering Program offers interdisciplinary M.S. and Ph.D. degrees through several departments, including Materials Science and Engineering. The program includes courses in materials, chemical engineering, chemistry, physics, and mechanical engineering. The MBA&E is an interdisciplinary degree program in business and engineering designed primarily for students with an undergraduate degree in engineering and two years or more of relevant work experience. The curriculum consists of an MBA core and electives (23 credits) and an engineering core and electives (18 credits), plus other electives and a project which integrates business and engineering (4 credits). Students wishing to have the engineering core in Materials Science and Engineering may enter this program through the Materials Science and Engineering Department.

SPECIAL PROGRAMS AND OPPORTUNITIES
The department has established specific recommended programs for the M.S., the M.Eng., and the Ph.D., emphasizing the following areas: metals processing and performance, ceramics and glass processing and properties, electronic and photonic materials, polymer modification, processing and characterization, biomaterials, electron microscopy and microstructural characterization. These programs are flexible and often interdisciplinary.

Major Requirements
A candidate for the M.S. completes a thesis, unless fully funded by industry, in which case a thesis is not required. M.S. thesis research normally represents six of the 30 semester hours required for this degree. Candidates for the M.Eng. complete a three-credit engineering project.

A candidate for the Ph.D. prepares a preliminary program of courses and research, providing for specialization in some field (largely through research) in consultation with the adviser. Prior to formal establishment of the doctoral program by the special committee and its approval by the college, the student passes a qualifying examination that must be taken in the first or second year of doctoral work. The department does not require a foreign language. It does require preparation and defense of a research proposal as a portion of the general examination.

Of the courses listed only those in the 300 series are available for graduate credit. There are many additional offerings in materials under the listings of other departments.

Most graduate students receive some form of financial aid. Several kinds of fellowships and assistantships are available. This type of aid generally provides for tuition, and a stipend. For details of graduate scholarships, fellowships, and assistantships, please refer to the Financial Aid (http://catalog.lehigh.edu/graduatetestudyandresearch/financialaid/) section.

Research Activities
Graduate students conduct their research in facilities located in the Department or other centers and institutes. The following list describes current Materials Science and Engineering research activities:

**Metals Processing and Performance**
Joining of metals and alloys, additive manufacturing, solidification modeling, deformation processing, grain boundary cohesion, high entropy materials.

**Ceramics and Glass Processing and Properties**
Fundamental studies of sintering and grain growth, novel reaction-based processing for bulk and thin film ceramics, microstructure and properties of oxides for environmental coatings, growth of single crystal piezoelectric ceramics, creep and grain boundary chemistry of alumina, dielectric and electrical properties of glasses, corrosion of glass.

**Electronic and Photonic Materials**
Thin films synthesis and characterization, novel wide-bandgap semiconductors, degradation processes in light-emitting semiconductors, bulk single crystal growth, reliability of MEMS materials, polymer packaging materials, glass nanosstructure and chemistry, glasses for nonlinear optical applications, transparent glass ceramics, photo-induced phenomena, and photovoltaics.

**Polymer Modification, Processing and Characterization**
Polymer conjugation and chemical modification, cure kinetics, melt compounding and extrusion, surface characterization, adhesion, additive manufacturing, degradation behavior, mechanical properties, and thermal analysis.

**Biomaterials**
Synthesis of biomaterials, biophysics, biomimicry, fabrication, chemical functionalization, characterization methods, biological materials, and application-driven design.

**Electron Microscopy and Microstructural Characterization**
Transmission electron microscopy, scanning electron microscopy, nanoscale compositional mapping, cathodoluminescence microscopy and spectroscopy, x-ray diffraction and fluorescence, x-ray microanalysis, electron-loss spectrometry, extended x-ray absorption and electron energy loss fine structure.

**Courses**

**MAT 010 Materials Laboratory 3 Credits**
Introduction to experimental methods used to fabricate and measure the structure and properties of materials. Thermal and mechanical processing and properties are emphasized. Specimen preparation and examination by light optical microscopy.

Prerequisites: MAT 033
Can be taken Concurrently: MAT 033

**MAT 020 Computational Methods in Materials Science 3 Credits**
The use of computers and computational methods to solve problems in materials science and engineering. Students will employ both commercial packages and their own code in order to complete assignments. Students will utilize word processing and display packages to present results of projects.

Prerequisites: ENGR 010

**MAT 028 Silicon, Steel, or Styrofoam? Designing with Materials 3 Credits**
A systematic methodology for selecting materials and fabrication processes in engineering design; case studies in which this methodology is used; overview of engineering materials and their properties; development of material performance indices; materials for environmentally conscious and sustainable design; industrial design considerations; design-directed development of new materials. No previous engineering experience required.

Prerequisites: PHY 009 and PHY 010 or PHY 011
Can be taken Concurrently: PHY 009, PHY 010, PHY 011

**MAT 033 Engineering Materials and Processes 3 Credits**
Application of physical and chemical principles to understanding, selection, and fabrication of engineering materials. Materials considered include metals, polymers, ceramics, composites, and electronic materials. Case studies of materials used range from transportation systems to microelectronic devices.
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<thead>
<tr>
<th>Course Code</th>
<th>Course Title</th>
<th>Credits</th>
<th>Repeat Status</th>
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<tbody>
<tr>
<td>MAT 101</td>
<td>Professional Development</td>
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<tr>
<td>MAT 107</td>
<td>Special Topics in Materials 1-3</td>
<td>1-3</td>
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</tr>
<tr>
<td>MAT 201</td>
<td>Physical Properties of Materials 3</td>
<td>3</td>
<td></td>
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<tr>
<td>MAT 203</td>
<td>Materials Structure at the Nanoscale 3</td>
<td>3</td>
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<tr>
<td>MAT 204</td>
<td>Processing and Properties of Polymeric Materials 3</td>
<td>3</td>
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<td>MAT 205</td>
<td>Thermodynamics of Macro/Nanoscale Materials 3</td>
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<td>MAT 206</td>
<td>Processing and Properties of Metals 3</td>
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<td>MAT 211</td>
<td>Capstone Design Project I 3</td>
<td>3</td>
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<td>MAT 212</td>
<td>Capstone Design Project II 2</td>
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<tr>
<td>MAT 214</td>
<td>Processing and Properties of Ceramic Materials 3</td>
<td>3</td>
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<tr>
<td>MAT 218</td>
<td>Mechanical Behavior of Macro/Nanoscale Materials 3</td>
<td>3</td>
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<tr>
<td>MAT 226</td>
<td>Failure Analysis Reports</td>
<td>3</td>
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<td>MAT 300</td>
<td>Apprentice Teaching</td>
<td>3</td>
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<tr>
<td>MAT 309</td>
<td>Composite Materials 3</td>
<td>3</td>
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<tr>
<td>MAT 310</td>
<td>Independent Study in Materials 1-3</td>
<td>3</td>
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**Prerequisites:**
- PHY 021 and MAT 033 and MATH 205
- CHM 030 and MAT 033 and MAT 010
- PHY 021 and MAT 033 and MATH 205
- MATH 023 and MAT 033
- MATH 023, MAT 033
- MATH 206, MAT 205
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**Course Description:**
- **MAT 101 Professional Development 2 Credits**
- **MAT 107 Special Topics in Materials 1-3 Credits**
- **MAT 201 Physical Properties of Materials 3 Credits**
- **MAT 203 Materials Structure at the Nanoscale 3 Credits**
- **MAT 204 Processing and Properties of Polymeric Materials 3 Credits**
- **MAT 205 Thermodynamics of Macro/Nanoscale Materials 3 Credits**
- **MAT 206 Processing and Properties of Metals 3 Credits**
- **MAT 211 Capstone Design Project I 3 Credits**
- **MAT 212 Capstone Design Project II 3 Credits**
- **MAT 214 Processing and Properties of Ceramic Materials 3 Credits**
- **MAT 218 Mechanical Behavior of Macro/Nanoscale Materials 3 Credits**
- **MAT 226 Failure Analysis Reports 3 Credits**
- **MAT 300 Apprentice Teaching 3 Credits**
- **MAT 309 Composite Materials 3 Credits**
- **MAT 310 Independent Study in Materials 1-3 Credits**
MAT 311 (BIOE 311) Introduction to Biomaterials 3 Credits
Application of materials science and engineering principles to biomedical materials with a focus on polymers, ceramics, and metals. Synthesis and fabrication of biomaterials, structure-property-function relationships related to biocompatibility and bioactivity; nano- to macro-scale characterization; material-tissue interactions; and applications of biomaterials including implants, devices, drug delivery, tissue engineering and regenerative medicine.
Prerequisites: MAT 033

MAT 314 (ME 314) Metal Forming Processes 3 Credits
Prerequisites: MAT 206

MAT 315 Physical Properties of Structural and Electronic Ceramics 3 Credits
Structure-property relationships in ceramics. Mechanical behavior including plasticity, hardness, elasticity, strength and toughening mechanisms. Thermal behavior including specific heat, thermal expansion, thermal conduction and thermal shock. Electrical behavior including application of tensors and crystal physics to electroceramics.
Prerequisites: MAT 214

MAT 316 Optical Properties of Materials 3 Credits
Interaction of electromagnetic waves with solid, liquid, and gaseous matter: reflection, refraction, polarization, diffraction, scattering, absorption, and luminescence. Factors determining the perceived color of metals, ceramics, polymers, semiconductors, biomaterials, and various nanostructured materials. Overview of the technological applications of optical materials in coatings, lighting, display technologies, lasers, solar cells, and optical communications. Credit will not be given for both MAT 316 and MAT 416.
Prerequisites: MAT 033

MAT 317 Imperfections in Crystals 3 Credits
The major types of crystal defects and their role in controlling the properties of materials. Point, line and planar defects, their atomic configurations and experimental techniques to study their characteristics. Emphasis on the role of dislocations and grain boundaries in the control of mechanical properties.
Prerequisites: MAT 203

MAT 318 (BIOE 318, CHE 318) Soft Materials: Rheology and Characterization 3 Credits
Characterization of soft materials using rheological techniques. Fundamentals of rheology and rheological characterization applied to materials such as polymers, glassy liquids and polymeric gels. Closed to students who have taken CHE/BIOE/MAT 418. Instructor permission or graduate status required.

MAT 319 Current Topics in Materials Science 3 Credits
Selected topics of current interest in the field of materials engineering but not covered in the regular courses. Consent of department required.
Repeat Status: Course may be repeated.

MAT 320 Analytical Methods in Materials Science 3 Credits
Selected topics in modern analysis and their application to materials problems in such areas as thermodynamics, crystallography, deformation and fracture, diffusions.
Prerequisites: MATH 231 or MATH 205

MAT 324 (BIOE 324) Introduction to Organic Biomaterials 3 Credits
Property, characterization, fabrication and modification of organic materials for biomedical and biological applications; host responses to biomaterials on the molecular, cellular and system level; general introduction to biosensors, drug delivery devices and tissue engineering. Consent of instructor required.
Prerequisites: BIOE 110 or MAT 204

MAT 325 (BIOE 325) Inorganic Biomaterials 3 Credits
Fabrication methods for biomedical implant and devices. Selection of metals and ceramics with specific bulk and surface physical as well as chemical properties. The role of materials chemistry and microstructure. Biocompatibility. Case studies (dental and orthopedic implants, stents, nonporous ceramic filters for kidney dialysis).
Prerequisites: MAT 033

MAT 326 (BIOE 326) Biomimetic and Bio-enabled Materials 3 Credits
The structure, function, properties and use of biopolymers, biocomposites, and biomaterials. Biomimetic materials design, including colloids, interfaces, macromolecules, and applications of such materials. Environmental and ethical considerations, such as degradation products when using biomimetic materials. Closed to students who have taken MAT 426 (BioE 426).
Prerequisites: MAT 033 or BIOE 110
Attribute/Distribution: ND

MAT 327 Industrial Project 4 Credits
Restricted to a small group of seniors and graduate students selected by the department from those who apply. Two full days per week are spent on development projects at the plant of an area industry, under the direction of a plant engineer and with faculty supervision.

MAT 329 Industrial Project 4 Credits
To be taken concurrently with MAT 327. Material is the same as MAT 327.

MAT 332 Basics of Materials Science and Engineering 3 Credits
Physical and chemical principles applied to understanding the structure, properties, selection, fabrication, and use of engineering materials: metals, polymers, ceramics, composites and electronic materials. Case studies of materials used ranged from transportation systems to microelectronic devices. Lectures and individual study assigned by graduate advisor. Must have graduate student status. Consent of department required. Not available to students who have taken MAT 333 or equivalent.

MAT 333 Crystallography and Diffraction 3 Credits
Introduction to crystal symmetry, point groups, and space groups. Emphasis on materials characterization by x-ray diffraction and electron diffraction. Specific topics include crystallographic notation, stereographic projections, orientation of single crystal, textures, phase identification, quantitative analysis, stress measurement, electron diffraction, ring and spot patterns, convergent beam electron diffraction (CBED), and space group determination. Applications in mineralogy, metallurgy, ceramics, microelectronics, polymers, and catalysts. Lectures and laboratory work. Senior standing in chemistry.
Prerequisites: MAT 203 or EES 133

MAT 334 (CHE 334) Electron Microscopy and Microanalysis 4 Credits
Fundamentals and experimental methods in electron optical techniques including scanning electron microscopy (SEM), conventional transmission (TEM) and scanning transmission (STEM) electron microscopy. Specific topics covered will include electron optics, electron beam interactions with solids, electron diffraction and chemical microanalysis. Applications to the study of the structure of materials are given. Consent of department required.

MAT 340 Research Techniques 3 Credits
Study and application of research techniques in materials science and engineering. Research opportunities, design of experimental programs, analysis of data, presentation of results. Selection of research topic and preparation and defense of research proposal. Restricted to a small number of students selected by the department from those who apply.

MAT 341 Undergraduate research 3 Credits
Application of research techniques to a team-based project in materials science and engineering selected in consultation with the faculty and advised by at least one faculty member in Materials Science and Engineering. Thesis writing in consultation with faculty advisor and mentors. Preceded by MAT 340. Department permission required.
Prerequisites: MAT 386 and MAT 486.

**Synthesis, morphology and properties of polymer nanocomposites.**

**MAT 386 Polymer Nanocomposites 3 Credits**

Synthesis, morphology and properties of polymer nanocomposites. Comparisons with traditional particulate composites will be made and models predicting properties will be emphasized. Melt viscosity, mechanical properties, barrier properties and flame retardancy will be discussed. Credit is not given for both MAT 386 and MAT 486.

Prerequisites: MAT 204 or MAT 393
MAT 411 (BIOE 411) Prerequisites: Graduate version of MAT 324 requiring additional assignments. Credit to biomaterials on the molecular, cellular, and system level; general materials for biomedical and biological applications; host responses to biomaterials on the molecular, cellular, and system level; general introduction to biosensors, drug delivery, and tissue engineering. Graduate version of MAT 324 requiring additional assignments. Credit is not given for both MAT 324 (BioE 324) and MAT 424 (BioE 424).


MAT 415 Mechanical Behavior of Ceramic Solids 3 Credits Strength, elasticity, creep, thermal stress fracture, hardness, abrasion and high-temperature deformation characteristics of single- and multicomponent brittle ceramic solids. Statistical theories of strength, static and cyclic fatigue, crack propagation, fracture toughness. Correlation of mechanical behavior, microstructure, and processing parameters.

MAT 416 Optical Properties of Materials 3 Credits Interaction of electromagnetic waves with solid, liquid, and gaseous matter: reflection, refraction, polarization, diffraction, scattering, absorption, and luminescence. Factors determining the perceived color of metals, ceramics, polymers, semiconductors, biomaterials, and various nanostructured materials. Overview of the technological applications of optical materials in coatings, lighting, display technologies, lasers, solar cells, and optical communications. Additional coursework will be required of students seeking the graduate level MAT 416 qualification. Credit will not be given for both MAT 316 and MAT 416.

MAT 417 (BIOE 417, CHE 417) Soft Materials: Mechanics and Physics 3 Credits Physical and mechanical behavior of soft materials such as gels, foams, rubbers, soft adhesives, and most biological tissue. Large strain kinematics, stress measures, constitutive relations from the molecular and continuum points of view, and application to problems such as cavitation, crazing, thin structures, fracture, adhesion, surface stress, and electroactive materials.

MAT 418 (BIOE 418, CHE 418) Soft Materials: Rheology and Characterization 3 Credits See the course description listed for CHE/BIOE/MAT 318. In order to receive 400-level credits, the student must do an additional, more advanced term project, as defined by the instructor at the beginning of the course. Closed to students who have taken CHE/BIOE/MAT 318.

MAT 423 Advanced Transmission Electron Microscopy 4 Credits The theory and practice of operation of the transmission and scanning transmission electron microscope. Techniques covered include bright field, high resolution and weak-beam dark field, lattice imaging, diffraction pattern indexing and Kikuchi line analysis. The theory of diffraction contrast is applied to the interpretation of electron micrographs. Specimen preparation techniques.

MAT 424 (BIOE 424) Introduction to Organic Biomaterials 3 Credits Property, characterization, fabrication, and modification of organic materials for biomedical and biological applications; host responses to biomaterials on the molecular, cellular, and system level; general introduction to biosensors, drug delivery, and tissue engineering. Graduate version of MAT 324 requiring additional assignments. Credit is not given for both MAT 324 (BioE 324) and MAT 424 (BioE 424).

MAT 425 (BIOE 425) Inorganic Biomaterials 3 Credits Fabrication methods for biomedical implant and devices. Selection of metals and ceramics with specific bulk and surface physical as well as chemical properties. The role of materials chemistry and microstructure. Biocompatibility. Case studies (dental and orthopedic implants, stents, nonporous ceramic filters for kidney dialysis). Graduate version of MAT 325; credit will not be given for both MAT 325 and MAT 425.

MAT 426 (BIOE 426) Biomimetic and Bio-enabled Materials 3 Credits This course is a graduate version of MAT 326 (BIOE 326). While the lecture content will be the same as the 300-level course, students enrolled in MAT 426 (BIOE 426) will have more advanced assignments. Closed to students who have taken MAT 326 (BIOE 326). Requirements: Graduate standing in Bioengineering or Materials Science and Engineering.

MAT 427 Advanced Scanning Electron Microscopy 4 Credits The theory and practice of operation of the scanning electron microscope and electron microprobe. Techniques covered will include high-resolution scanning, quantitative electron probe microanalysis. Electron beam sample interactions, X-ray spectrometry, and electron optics will be discussed in detail.

MAT 430 Glass Science 3 Credits Definition and formation of glass. Structure of common inorganic (including metallic) and polymeric glass systems. Methods of glass making. Phase separation of devitrification. Physical properties including diffusion, electrical conductivity, chemical durability, and optical and mechanical properties. Special products including glass ceramics, optical fibers, photosensitive glasses, etc. Visit to a glass manufacturing plant may also be included.

MAT 431 Sintering Theory and Practice 3 Credits Science and technology of the sintering of solid-state materials. Driving force and variables. Critical review of the sintering models. Coverage of single phase, multiphase and composite systems. Special sintering techniques such as fast firing, rate controlled sintering, hot pressing and transient second-phase sintering. Sintering of specific ceramic and metal systems.

MAT 442 Inorganic Glasses 3 Credits Definition, formation and structure of glass; common glass systems; manufacturing processes; optical, mechanical, electrical and dielectric properties; chemical durability; glass fibers and glass ceramics. Lectures and laboratories. Credit is not given for both MAT 342 and MAT 442.

MAT 443 (CHM 443) Solid-State Chemistry 3 Credits This solid state chemistry course will introduce students into symmetry of extended solids, X-ray crystallography of solids, crystal structures, band theory, electronic and ionic conductivity in solids, defects in solids, silicate chemistry and nonporous solids.

MAT 445 Additive Manufacturing and Powder Metallurgy 3 Credits Application of powder metallurgy in emerging technologies in the field of Additive Manufacturing (aka 3-D Printing). Metal powder fabrication and characterization methods. Powder processing including powder compaction, theory of compacting, press and die design, sintering, hot consolidation and additive manufacturing. Microstructure and properties of sintered materials and their relationship to processing conditions. Industrial applications. Emerging powder metallurgy technologies. Graduate version of MAT 345 requiring additional assignments. Credit is not given for both MAT 345 and MAT 445.
MAT 455 Materials for Nanotechnology 3 Credits
An introduction to the nanoworld and how we observe the nanoworld through transmission electron microscopy. Other topics include: probing nanosurfaces, carbon as a nanomaterial, fullerences, carbon nanotubes, metal clusters, metal nanoparticle preparation, and directed self-assembly of nanoparticles. Also discussed are the thermal, chemical, electronic, optical, and magnetic properties of metal nanoparticles, nanowires, semiconductor nanoparticles, and inorganic nanoparticles.

MAT 456 Strategies for Nanocharacterization 3 Credits
Lectures describe various nanocharacterization techniques in terms of which technique is best for specific measurements on nanostructures less than 100 nm in extent. Special attention is paid to spatial resolution and detection limits for SEM, TEM, X-ray analysis, diffraction analysis, ion beam techniques, surface techniques, AFM and other SPMs, and light microscopies and spectroscopies.

MAT 459 Thin Film Deposition, Processing, and Characterization 3 Credits
Thin films are at the heart of electronics, optics, medicine, and nanotechnology. Fundamental and applied aspects of thin film deposition, processing, and characterization. Growth methods including physical and chemical deposition techniques. Equipment and hardware for deposition and analysis. Structural, mechanical, electronic, and chemical properties of films. Processing methods and their relationship to specific applications. Graduate version of MAT 359 with extra assignments for graduate students. Credit will not be given for both MAT 359 and MAT 459.

MAT 460 Engineering Project 1-6 Credits
In-depth study of a problem in the area of materials engineering or design. The study is to lead to specific conclusions and be embodied in a written report. Intended for candidates for the M.Eng. Repeat Status: Course may be repeated.

MAT 462 Independent Study 1-4 Credits
An intensive study, with report, of a topic in materials science and engineering which is not treated in other courses. Consent of instructor required. Repeat Status: Course may be repeated.

MAT 463 Computational Methods in Science and Engineering 3 Credits
Computer simulation of systems at various length and time scales. Atomistic simulation (molecular dynamics and Monte Carlo) methods are presented and applied to models described by simple interatomic potentials. Mesoscale simulation is described in the context of domain growth and, at the continuum scale, finite-difference and finite-element methods are employed to model heat conduction and mass diffusion. Lecture and computer laboratory sessions. Extra assignments provided to graduate students. Credit will not be given for both MAT363 and MAT463.

MAT 482 (CHE 482, CHM 482) Mechanical Behaviors of Polymers 3 Credits
A treatment of the mechanical behavior of polymers. Characterization of experimentally observed viscoelastic response of polymeric solids with the aid of mechanical model analogs. Topics include time-temperature superposition, experimental characterization of large deformation and fracture processes, polymer adhesion, and the effects of fillers, plasticizers, moisture and aging on mechanical behavior.

MAT 483 (CHE 483, CHM 483) Emulsion Polymers 3 Credits
Examination of fundamental concepts important in the manufacture, characterization, and application of polymer latexes. Topics to be covered will include colloidal stability, polymerization mechanisms and kinetics, reactor design, characterization of particle surfaces, latex rheology, morphology considerations, polymerization with functional groups, film formation and various application problems.

MAT 485 (CHE 485, CHM 485) Polymer Blends 3 Credits
Synthesis, morphology, and mechanical behavior of polymer blends. Polymer/polymer miscibility and thermodynamics of mixing of polymer/solvent and polymer/polymer blends. Prediction of miscibility using various theoretical models and methods that can be used to help enhance miscibility (H bonding etc.). Methods to enhance the compatibility of polymer/polymer blends (e.g., block copolymers, ternary addition, IPNs, etc.). Types of polymer blends. Must have completed any introductory polymer course or equivalent.

MAT 486 Polymer Nanocomposites 3 Credits
Synthesis, morphology and properties of polymer nanocomposites. Comparisons with traditional particulate composites will be made and models predicting properties will be emphasized. Melt viscosity, mechanical properties, barrier properties and flame retardancy will be discussed. This course is a version of MAT 386 for graduate students, with additional research projects and advanced assignments. Closed to students who have taken MAT 386. Credit is not given for both MAT 386 and MAT 486. Prerequisites: MAT 204 or MAT 393 or MAT 399.

MAT 487 Adhesion and Adhesives Technology 3 Credits
Basics of intermolecular forces, surface science, and mechanics of materials and how these relate to adhesion. Processing and design of adhesive joints. Formulation and behavior of pressure sensitive and structural adhesives. Background in polymers is helpful.

MAT 490 Thesis 1-6 Credits
Repeat Status: Course may be repeated.

MAT 492 (CHE 492, CHM 492) Topics in Polymer Science 1-3 Credits
Intensive study of topics selected from areas of current research interest such as morphology and mechanical behavior, thermodynamics and kinetics of crystallization, new analytical techniques, molecular weight distribution, non-Newtonian flow behavior, second-order transition phenomena, novel polymer structures. Credit above three hours is granted only when different material is covered.

MAT 499 Dissertation 1-15 Credits
Repeat Status: Course may be repeated.