Materials Science and Engineering

Materials Science and Engineering provides the skills to discover, improve, and test new materials to enable advanced engineering technologies to address the most complex problems of the society. From space exploration to sustainable packaging, MSE is the leading engineering degree when it comes to the development of a safe and clean future. Lectures and laboratories with strong computational fundamentals will equip students to understand complex issues and challenges of materials' performance and how to design effective engineering solutions.

The **undergraduate program** in Materials Science and Engineering brings the foundation of materials engineering, educating students using engaging project-oriented methodologies. The curriculum covers from the foundations to application of materials in advanced technologies, such as materials for energy applications, including batteries and solar cells, to structural composites for vehicles and space exploration. The curriculum offers a 4-year degree with extensive opportunities for research experience, internships, and a number of hands-on laboratories integrating novel computational tools with processing techniques such as 3D printing and selective laser sintering. The program also offers a 4+1 opportunity, with a masters degree in the field with only 1 additional year of study.

The **graduate program** in Materials Science and Engineering offers advanced education for those interested in research and the development of their careers. Certificate, Master's, and Ph.D. programs build on each other to deliver complementary levels of education. Taking advantage of the strong research-oriented faculty at Lehigh University, students will engage and learn by experimenting research at the forefront of knowledge. The program is suitable for materials engineers to further advance in the field, but also for engineers from other areas, such as mechanical, electrical and bioengineering, so they can learn to navigate the complex challenges involving materials engineering solutions.

For more information please visit us at: https://materials.lehigh.edu/ **(**https://engineering.lehigh.edu/matsci/**)**

B.S. IN MATERIALS SCIENCE AND ENGINEERING

The undergraduate program in Materials Engineering is designed to prepare you to address the most challenging societal problems by giving you the tools to create, manipulate, test and invent new materials. You'll be prepared for operations, management, research, development, 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, some also work as 'general' 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:

MAT 033	Engineering Materials and Processes	3
MAT 10 or MAT 028 may be used as an elective. The remaining courses may be chosen from a list of 200 and 300 level courses relevant to various engineering disciplines. List is maintained by the department.		12
Total Credits		**15**

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:

MAT 355	Materials for Nanotechnology	3
One course on crystallography and band theory		3
Additional electives		9
Total Credits		**15**

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	Credits	Second Semester	Credits
MATH 021	4	MATH 022	4
WRT 001	3	WRT 002	3
ENGR 005	2	PHY 011[1]	4
ENGR 010	2	PHY 012[1]	1
CHM 030[1]	4	Select one of the following:	4
		ECO 001	4
		Humanities or Social Sciences Elective	4
	15		**16**
Second Year			
First Semester	Credits	Second Semester	Credits
MAT 033[2]	3	MAT 203	3
MAT 010	3	MAT 205	3
MATH 023	4	MAT 218	3
PHY 021	4	MAT 204	3
PHY 022	1	Humanities or Social Science Elective	3
Free Elective	3		
	18		**15**
Third Year			
First Semester	Credits	Second Semester	Credits
MAT 020	3	MAT 206	3
MAT 216	3	MAT 214	3
MAT 101	2	MAT 201	3
MATH 205	3	Engineering Science Elective	3
MECH 003	3	Free Elective	3
Select one of the following:	4	MAT 211	3
ECO 001	4		
Humanities or Social Science Elective	4		
	18		**18**
Fourth Year			
First Semester	Credits	Second Semester	Credits
MAT 252	3	MAT 268	3
Engineering Science Elective	3	CHE 280	3
Approved Elective	3	ECE 083	3
Humanities or Social Science Elective	4	ECE 162	1
MAT 212	2	Free Elective	3
		Humanities or Social Science Elective	4
	15		**17**

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/graduatestudyandresearch/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 nanostructure 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 0,3 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 0,3 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 0,3 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.

MAT 101 Professional Development 2 Credits

The role and purpose of engineering in society; the meaning of being a professional; engineering ethics; environmental issues; safety issues; communications and decision-making in the engineering process; expectations and problems of young engineers; personal goals; choosing a career. Required reading. Written reports based on library research.

MAT 107 Special Topics in Materials 1-3 Credits

A study of selected topics in materials science and engineering not covered in other formal courses. Consent of instructor required.

MAT 201 Physical Properties of Materials 3 Credits
Basic concepts of modern physics and quantum mechanics needed for an understanding of electrons in solids. The experimental development leading to wave mechanics is emphasized. Uses of the Schrodinger equation as the basis for the free electron theory of metals and band theory. Optical properties are developed leading to a discussion of lasers.
Prerequisites: PHY 021 and MAT 033 and MATH 205

MAT 203 Materials Structure at the Nanoscale 0,3 Credits
The structure of metals, ceramics, semiconductors, and polymers at the atomic scale. Crystalline, semicrystalline, liquid crystalline and amorphous (glassy) states. Fundamental aspects of formal crystallography and crystal structures. Point, line, and planar crystal defects. Materials characterization by x-ray diffraction, light microscopy, electron microscopy, and other techniques.
Prerequisites: CHM 030 and MAT 033 and MAT 010
Can be taken Concurrently: MAT 033

MAT 204 Processing and Properties of Polymeric Materials 0,3 Credits
The structure-property relationships in polymers will be developed, emphasizing the glass transition, rubber elasticity, crystallinity, and mechanical behavior. Elements of polymer processing. Extrusion of plastics and films, and fiber spinning operations.
Prerequisites: MAT 033

MAT 205 Thermodynamics of Macro/Nanoscale Materials 3 Credits
The three laws of thermodynamics. Gibbs free energy and conditions of equilibrium. Effects of scale on material behavior. Binary and ternary equilibrium phase diagrams. Application of thermodynamics to materials problems, with examples from nanotechnology, biotechnology, and structural materials.
Prerequisites: MATH 023 and MAT 033
Can be taken Concurrently: MATH 023, MAT 033

MAT 206 Processing and Properties of Metals 3 Credits
The production and purification of metals, their fabrication, and control of their properties. Includes topics such as precipitation hardening, hot and cold working, and casting.
Prerequisites: MAT 218 and MAT 216

MAT 211 (BIOC 211, BIOE 211, ENGR 211, ME 211) Capstone Design Project I 3 Credits
Students work on teams, integrating knowledge and skills acquired in their prior course work, to design practical solutions to real-world problems, typically in collaboration with industry, entrepreneurs, faculty, or campus departments. Teams perform in-depth engineering design while considering engineering standards and the project business case. Constraints, including technical, financial, environmental, societal, supply chain, regulatory, and others are considered throughout. Teams produce written reports, oral presentations, and prototypes appropriate for the project.
Prerequisites: MAT 010 and MAT 033 and MAT 205 and MAT 218 and MAT 203
Can be taken Concurrently: MAT 203

MAT 212 (BIOC 212, BIOE 212, ENGR 212, ME 212) Capstone Design Project II 2 Credits
Students continue developing their solutions from MAT 211 through prototype fabrication and testing, iteration, and failure mode analysis. New information about the project, as well as new knowledge, standards, and constraints, may be identified, considered and integrated into the solution. Teams are expected to produce a final project-specific prototype, an implementation plan appropriate to the project, as well as related business case financial models. Additional deliverables include written reports and presentations.
Prerequisites: MAT 211 and MAT 216
Can be taken Concurrently: MAT 216

MAT 214 Processing and Properties of Ceramic Materials 0,3 Credits
General overview of the compositions, properties and applications of ceramic materials. The theory and practice of fabrication methods for ceramics and glasses. Methods of characterization. Selected properties of ceramic materials.
Prerequisites: MAT 033

MAT 216 Diffusion and Phase Transformations 0,3 Credits
Fundamental diffusion equations; liquid-solid transformations; solid-solid transformations; transformation kinetics; metastable transformations; diffusionless transformations; examples of various transformations in different materials and their effect on properties.
Prerequisites: MAT 203 and MAT 205

MAT 218 Mechanical Behavior of Macro/Nanoscale Materials 0,3 Credits
Elasticity, plasticity, and fracture of metals, ceramics, polymers, and composites. The roles of defects and size scale on mechanical response. Strengthening and toughening mechanisms in solids. Statics and time-dependent failures from microstructural and fracture mechanics viewpoints. Lectures and laboratories.
Prerequisites: MAT 033 and MAT 010

MAT 252 Electronic Properties of Materials 3 Credits
Electronic structure of materials, i.e., band and zone theory, is presented from a physical point of view. Electrical conductivity in metals, semiconductors, insulators and superconductors discussed. Simple semiconductor devices reviewed. Magnetic properties examined in the context of domain theory and applications. Optical and dielectric properties of semiconductors and ferroelectrics are considered.
Prerequisites: MAT 201 and MAT 203

MAT 268 Failure Analysis Reports 3 Credits
Application of chemical and mechanical failure concepts, microstructural analysis, and fracture surface characterization to the analysis and prevention of engineering component failures. Materials selection from databases of AISI standard alloys. Laboratory investigations on component failures using ASTM standard testing methods. Written and oral presentations of the results. Must have senior standing.
Prerequisites: MAT 204 and MAT 206 and MAT 214

MAT 300 Apprentice Teaching 3 Credits

MAT 309 (ME 309) Composite Materials 3 Credits
Principles and technology of composite materials. Processing, properties, and structural applications of composites, with emphasis on fiber-reinforced polymers.
Prerequisites: MAT 033 or MECH 003

MAT 310 Independent Study in Materials 1-3 Credits
Provides an opportunity for advanced, independent study of selected topics in materials science and engineering not covered in other formal courses.
Repeat Status: Course may be repeated.

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
Mechanical metallurgy and mechanics of metal forming processes. Yield criteria. Workability. Friction and lubrication. Engineering analysis of forging, extrusion, wire and tube drawing, rolling, sheet forming and other processes. Recent developments in metal forming. Credit is not given for both MAT 314 and MAT 414.
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, diffusion.
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 biominerals. 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 0,3 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 033 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 0,4 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.

MAT 342 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.
Prerequisites: MAT 033

MAT 345 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. Credit will not be given for both MAT 345 and MAT 445.
Prerequisites: MAT 206 or ISE 215 or ME 240

MAT 346 Physical Metallurgy of Welding 3 Credits
Operational characteristics of welding processes. Application of solidification and solid state transformation theory to understanding microstructural development in welds, and influence of welding on properties. Metallurgical defects in welds. Computational techniques for predicting heat flow and phase transformations in welds of complex engineering alloys. Laboratory demonstrations.
Prerequisites: MAT 216

MAT 350 Effective Scientific Communication: Proposals, Figures, Papers, and Presentations 2 Credits
Effective communication is essential for scientists and engineers. In this course we discuss best practices for effective communication in the form of proposals, figures, presentations, and manuscripts. Students will develop their own materials based on their current or prior work that will undergo peer- and faculty-review. This course is targeted for first- and second-year graduate students but senior undergraduate students intent on attending graduate school may also enroll.
Repeat Status: Course may be repeated.

MAT 355 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, fullerenes, 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 356 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 359 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. Must have Junior or Senior level standing.

MAT 363 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. Credit will not be given for both MAT363 and MAT463.

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 388 (CHE 388, CHM 388) Polymer Characterization 3 Credits
Description of molecular weight measurements using dilute solutions (solution viscosity, size exclusion chromatography, osmotic pressure, and light scattering). Introduction to polymer thermal analysis techniques such as differential scanning calorimetry (DSC) , dynamic mechanical analysis (DMA), and thermomechanical analyzer (TMA). Discussion of structure and morphology of polymers and polymer blends using nuclear magnetic resonance (NMR), infrared spectroscopy (IR), Raman spectroscopy, UV analysis, transmission electron microscopy (TEM), scanning electron microscopy (SEM), atomic force microscopy (AFM). Crystallinity measurements using SANS, SAXS, and WAXS.
Prerequisites: MAT 033 or MAT 204 or MAT 392 or MAT 393

MAT 392 (CHE 392) Introduction to Polymer Science 3 Credits
Introduction to concepts of polymer science. Kinetics and mechanism of polymerization, synthesis and processing of polymers, characterization. Relationship of molecular conformation, structure and morphology to physical and mechanical properties.

MAT 393 (CHE 393, CHM 393) Physical Polymer Science 3 Credits
Structural and physical aspects of polymers (organic, inorganic, natural). Molecular and atomic basis for polymer properties and behavior. Characteristics of glassy, crystalline, and paracrystal-line states (including viscoelastic and relaxation behavior) for single- and multi-component systems. Thermodynamics and kinetics of transition phenomena. Structure, morphology, and behavior. Available to graduate and undergraduate students (with senior level standing) in CHE, CHEM or MAT.

MAT 401 Thermodynamics 0,3 Credits
Fundamentals of thermodynamics, as related to materials processes, including both hard and soft materials. Coverage of topics in classical and statistical thermodynamics, including the laws of thermodynamics, conditions of equilibrium, free energies, and thermodynamics of surfaces and phase transitions.

MAT 402 (ME 402) Advanced Manufacturing Science 3 Credits
The course focuses on the fundamental science-base underlying manufacturing processes, and applying that science base to develop knowledge and tools suitable for industrial utilization. Selected manufacturing processes representing the general classes of material removal, material deformation, material phase change, material flow, and material joining are addressed. Students create computer-based process simulation tools independently as well as utilize leading commercial process simulation packages. Laboratory experiences are included throughout the course.

MAT 403 Structure/Property Relations 4 Credits
Structure of materials and relationship to properties. Crystal structures and crystalline defects, structure in biological systems, amorphous materials, microstructure, and relationships to mechanical and other properties.

MAT 405 Kinetics 3 Credits
Derivation of fundamental diffusion equations and their application to single and multicomponent systems. Theoretical models of nucleation and growth (including spinodal decomposition), atomistic description of diffusion, influence of concentration/potential gradients and effects of temperature and pressure, and comparison with experimental observations. Kinetics of solid-state transformations, including phase transformations and particle coarsening.

MAT 406 Solidification 3 Credits
Structure, theory and properties of liquids. Homogeneous and heterogeneous nucleation theory and experimental results. Solidification phenomena in pure, single and multiphase materials including the nature of the freezing interface, segregation, constitutional super-cooling, dendritic growth, crystallographic effects, the origin of defects, crystal growing, zone processes. Consent of department chair required.

MAT 409 Current Topics in Materials 3 Credits
Recent practical and theoretical developments in materials. This course may be repeated for credit if new material is covered. Consent of department required.
Repeat Status: Course may be repeated.

MAT 411 (BIOE 411) Introductions 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. MAT 411 will require project-based study. Credit will not be given for both MAT 311 and MAT 411.
Prerequisites: MAT 033

MAT 414 Metal Forming Processes 3 Credits
Mechanical metallurgy and mechanics of metal forming processes. Yield criteria. Workability. Friction and lubrication. Engineering analysis of forging, extrusion, wire and tube drawing, rolling, sheet forming, and other processes. Recent developments in metal forming. Graduate version of MAT 314 requiring additional assignments. Credit is not given for both MAT 314 and MAT 414.
Prerequisites: MAT 206

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 work will be required of students seeking the graduate level MAT 416 qualification. Credit will not be given for both MAT 316 and MAT 416.
Prerequisites: MAT 033

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, creasing, thin structures, fracture, adhesion, surface stress, and electroactive materials.
Prerequisites: CHE 452 or ENGR 452

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 0,4 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.
Prerequisites: MAT 334

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).
Prerequisites: MAT 033

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.
Prerequisites: MAT 033

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.
Attribute/Distribution: ND

MAT 427 Advanced Scanning Electron Microscopy 0,4 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.
Prerequisites: MAT 334

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 nonoporous 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 450 Effective Scientific Communication: Proposals, Figures, Papers, and Presentations 2 Credits
Effective communication is essential for scientists and engineers. In this course we discuss best practices for effective communication in the form of proposals, figures, presentations, and manuscripts. Students will develop their own materials based on their current or prior work that will undergo peer- and faculty-review. This course is targeted for first- and second-year graduate students but senior undergraduate students intent on attending graduate school may also enroll.
Repeat Status: Course may be repeated.

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, fullerenes, 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 393

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 488 Polymer Characterization 3 Credits
Description of molecular weight measurements using dilute solutions (solution viscosity, size exclusion chromatography, osmotic pressure, and light scattering). Introduction to polymer thermal analysis techniques such as differential scanning calorimetry (DSC), dynamic mechanical analysis (DMA), and thermomechanical analyzer (TMA). Discussion of structure and morphology of polymers and polymer blends using nuclear magnetic resonance (NMR), infrared spectroscopy (IR), transmission electron microscopy (TEM) and atomic force microscopy (AFM).
Prerequisites: MAT 392 or MAT 393

MAT 489 Polymer Coatings 3 Credits
Film formation from solution and dispersion, and applications of coatings, mechanisms and kinetics of cured polymer systems, discussions of the variety of different types of coatings systems and their different applications; the methods used to characterize and test the coating; various methods used to process the polymers into a final coating and To examine in detail the various components that comprise a given polymer coating.
Prerequisites: MAT 392 or MAT 392

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 494 Polymer Thermodynamics 3 Credits
Applications of thermodynamics in polymer science and engineering. Topics include: the thermodynamic basis for preparing polymer solutions, polymer blends and polymer composites, the importance of miscibility, phase separation and mechanical compatibilization of polymer solutions, polymer blends, etc., the methods used to characterize the role of thermodynamics; discussion of various thermodynamic models used to predict polymer compatibility and understand the importance of free energy of mixing. Understand the importance of thermodynamics in different application such as polymer crystallization, liquid polymers, etc.
Prerequisites: MAT 392 or MAT 393

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