DEPARTMENT OF MACROMOLECULAR SCIENCE AND ENGINEERING

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http://polymers.case.edu  
Phone: 216.368.4172; Fax: 216.368.4202  
Gary Wnek, Professor and Chair  
gary.wnek@case.edu

Macromolecular science and engineering is the study of the synthesis, structure, processing, and properties of polymers. These giant molecules are the basis of synthetic materials including plastics, fibers, rubber, films, paints, membranes, and adhesives. Research is constantly expanding these applications through the development of new high performance polymers, e.g. for engineering composites, electronic, optical, and biomedical uses. In addition, most biological systems are composed of macromolecules—proteins (e.g. silk, wool, tendon), carbohydrates (e.g. cellulose) and nucleic acids (RNA and DNA) are polymers and are studied by the same methods that are applied to synthetic polymers.

Production of polymers and their components is central to the chemical industry, and statistics show that over 75 percent of all chemists and chemical engineers in industry are involved with some aspect of polymers. Despite this, formal education in this area is offered by only a few universities in this country, resulting in a continued strong demand for our graduates upon completion of their BS, MS, or PhD degrees.

Mission

To educate students who will excel and lead in the development of polymeric materials and the application of structure-property relationships. The department seeks to prepare students for either professional employment or advanced education, primarily in this or related science or engineering disciplines, but also in professional schools of business, law or medicine. Undergraduate students are offered opportunities for significant research experience, capitalizing on the strength of our graduate program.

Research

The research activities of the department span the entire scope of macromolecular science and polymer technology.

Synthesis

New types of macromolecules are being made in the department’s synthesis laboratories. The emphasis is on creating polymers with novel functional properties such as photoconductivity, selective permeation, and biocompatibility, and in producing new materials which behave like classical polymers without being linked together by covalent bonds.

Physical Characterization

This is the broad area of polymer analysis, which seeks to relate the structure of the polymer at the molecular level to the bulk properties that determine its actual or potential applications. This includes characterization of polymers by infrared, Raman, and NMR and mass spectroscopy, thermal and rheological analysis, determination of structure and morphology by x-ray diffraction, electron microscopy, and atomic force microscopy, permeability and free volume, and investigation of molecular weights and conformation by light scattering.

Mechanical Behavior and Analysis

Polymeric materials are known for their unusual mechanical capabilities, usually exploited as components of structural systems. Analysis includes the study of viscoelastic behavior, yielding and fracture phenomena and a variety of novel irreversible deformation processes.

Processing

A major concern of industry is the efficient and large scale production of polymer materials for commercial applications. Research in this area is focusing on reactive processing, multi-layer processing and polymer mixing, i.e., compounding and blends. The integration of sensors and processing equipment, and methods for examining changes in structure and composition during processing steps are growing areas of inquiry. Both laboratory and simulation research are brought to bear on these critical issues.

Materials Development and Design

Often, newly conceived products require the development of polymeric materials with certain specific properties or design characteristics. Materials can be tailor-made by designing synthesis and processing conditions to yield the best performance under specified conditions. Examples might be the design of photoluminescent and semi-conducting polymers for use in optoelectronic devices, polymers that are stable at high temperatures for fire-retardant construction materials, high temperature polymer electrolytes for use in advanced fuel cells, low density thermal insulating polymer composite materials, advanced polymeric optical devices, and biocompatible polymers for use in prosthetic implants, reconstructive medicine and drug-delivery vehicles.

Biopolymers

Living systems are composed primarily of macromolecules, and research is in progress on several projects of medical relevance. The department has a long-standing interest in the hierarchical structure and properties of the components of connective tissues (e.g., skin, cartilage, and bone). The department is also engaged in the development of new biocompatible polymers for applications in human health.

Faculty

Gary Wnek, PhD  
(University of Massachusetts, Amherst)  
The Joseph F. Toot, Jr. Professor and Chair

Polymeric biomaterials for drug delivery and regenerative medicine; nano- and micro-fiber fabrication; bio-mimicking approaches for polymer flammability mitigation; polymer packaging systems design; polyelectrolyte gels and elastomers; physiologically-mimicking macromolecular constructs with attention to primitive motile and irritable systems.
Eric Baer, DEng
(Johns Hopkins University)

**Director, Centered for Layered Polymeric Systems (CLiPS) and Herbert Henry Dow Professor of Science and Engineering**

Multilayered and ultrathin polymer films and devices. Irreversible microdeformation mechanisms; pressure effects on morphology and mechanical properties; relationships between hierarchical structure and mechanical function; mechanical properties of soft connective tissue; polymer composites and blends; polymerization and crystallization on crystalline surfaces; viscoelastic properties of polymer melts; damage and fracture analysis of polymers and their composites. Structure-property relationships in biological systems

Michael Hore, PhD
(University of Pennsylvania)

**Associate Professor**

Polymer physics; neutron scattering; polymer nanocomposites; grafted polymers and brushes; theory and modeling; self-consistent field theory; structure-property relationships; reconfigurable materials.

Hatsuo Ishida, PhD
(Case Western Reserve University)

**Professor**

Processing of polymers and composite materials; structural analysis of surfaces and interfaces; molecular spectroscopy of synthetic polymers

João Maia, PhD
(University of Wales Aberystwyth, U.K.)

**Associate Professor**

Polymer rheology: extensional rheology and rheometry; micro- and nano-rheology; bio-rheology: food rheology and processing; rheology for macromolecular technology: development and optimization of polymer blends and composites; viscoelasticity of micro- and nano-layered polymer films; on- and in-line monitoring of extrusion-based processes; micro-processing; environmental rheology and processing

Ica Manas-Zloczower, DSc
(Israel Institute of Technology)

**Professor**

Structure and micromechanics of fine particle clusters; interfacial engineering strategies for advanced materials processing; dispersive mixing mechanisms and modeling; design and mixing optimization studies for polymer processing equipment through flow simulations

Svetlana Morozova
(University of Massachusetts, Amherst)

**Assistant Professor**

Polymer dynamics

Valentin Rodionov, PhD
(Scripps Res. Institute)

**Assistant Professor**

Organic polymer chemistry; synthesis of novel macromolecular structures and architectures; catalysis

Lei Zhu, PhD
(University of Akron)

**Professor**

Nanoscale structure and morphology of crystalline/liquid crystalline polymers and block copolymers; ferroelectric and dielectric polymers for electric energy storage; polymer/inorganic hybrid nanocomposites; biodegradable polymers for diagnostic and drug delivery

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**Secondary Faculty**

James M. Anderson, PhD
(Oregon State University, M.D.)

**Professor of Macromolecular Science, Pathology, and Biomedical Engineering**

Biocompatibility, inflammation, foreign body reaction to medical devices, prostheses, and biomaterials

Donald Feke, PhD
(Princeton University)

**Professor of Chemical Engineering and Macromolecular Science**

Fine-particle processing, colloidal phenomena, dispersive mixing, and acoustic separation methods

Roger French, PhD
(Massachusetts Institute of Technology)

**F. Alex Nason Professor of Materials Science**

Optical materials and elements, optical properties and electronic structure of materials, and electrodynamic van der Waals-London dispersion interactions

John Protasiewicz, PhD
(Cornell University)

**Professor of Chemistry**

Inorganic, organic, main group, materials, polymer, catalysis, organometallic chemistry, and X-ray crystallography

Charles Rosenblatt, PhD
(Harvard University)

**Professor of Physics**

Modern optics and condensed matter experiment and nonlinear optics

Philip Taylor, PhD
(Cambridge University, England)

**Perkins Professor of Physics**

Phase transitions and equations of state for crystalline polymers; piezoelectricity and pyroelectricity

Horst von Recum, PhD
(University of Utah, Salt Lake City)

**Assistant Professor of Biomedical Engineering**

Novel platforms for the delivery of molecules and cells and the use of novel stimuli-responsive polymers for use in gene and drug delivery

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**Adjunct Faculty**

Thomas Chapin, PhD
(University of Connecticut)

**Vice President, UL Laboratories**

Polymer Flammability

Lashanda Korley, PhD
(Massachusetts Institute of Technology)

**Associate Professor, Chemical Engineering and Materials Science and Engineering University of Delaware**

Hierarchical peptide polymer hybrids; new fiber manufacturing strategies for functional material development; responsive composites; interplay of covalent and non-covalent interactions
Jon Pokorski, PhD  
(Northwestern University)  
*Associate Professor*  
Biomaterials for delivery of therapeutic proteins; protein-polymer conjugates; drug-delivery; biopolymer catalysts; self-assembling peptides; affinity-based delivery of therapeutics; layered polymeric delivery systems

Stuart Rowan, PhD  
(University of Glasgow)  
*Professor, The Institute for Molecular Engineering, University of Chicago*  
Supramolecular chemistry; synthesis of metallosupramolecular and stimuli-responsive polymers; isolation and utilization of cellulose nanocrystals in biomimetic and porous systems; reversible covalent chemistry

Christoph Weder, DrScNat  
(ETH Zurich Switzerland)  
*Professor of Polymer Chemistry and Materials and Director, Adolphe Merkle Institute of the University of Fribourg, Switzerland*  
Design, synthesis and investigation of structure-property relationships of novel functional polymers: polymers with unusual optic and/or electronic properties; (semi)conducting conjugated polymers; stimuli-responsive polymers; biomimetic materials, polymer nanocomposites, supramolecular chemistry

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**CWRU/Brazil Dual PhD Degree Adjunct Professors**

Rosario Elida Suman Bretas, PhD  
(Federal University of Sao Carlos)  
*Professor*  
Department of Materials Engineering

Veronica Maria de Araujo Calado, PhD  
(Federal University of Rio de Janeiro)  
*Professor*  
Department of Materials Engineering

Sebastiao Vicente Canevarolo Junior, PhD  
(Federal University of Sao Carlos)  
*Professor*  
Center for Exact and Technology, Dept of Materials Engineering

Leonardo Bresciani Canto, PhD  
(Federal University of Sao Carlos)  
*Professor*  
Department of Materials Engineering

Marcio da Silveira Carvalho, PhD  
(Pontificial Catholic University of Rio de Janeiro)  
*Professor*  
Department of Mechanical Engineering

Osvaldo de Lazaro Casagrande Junior, PhD  
(Federal University of Rio Grande do Sul)  
*Professor*  
Department of Organic Chemistry

Jose Roberto Moraes d’Almeida, PhD  
(Federal University of Rio de Janeiro)  
*Professor*  
Department of Chemical Engineering

Griselda Barrera Galland, PhD  
(Federal University of Rio Grande do Sul)  
*Professor*  
Institute of Chemistry

Aurora Perez Gramatges, PhD  
(Pontificial Catholic University of Rio de Janeiro)  
*Professor*  
Department of Chemistry

Elizabete Fernandes Lucas, PhD  
(Federal University of Rio de Janeiro)  
*Professor*  
Institute of Macromolecules

Raquel Santos Mauler, PhD  
(Federal University of Rio Grande do Sul)  
*Professor*  
Department of Organic Chemistry

Paulo de Souza Mendes, PhD  
(Pontificial Catholic University of Rio de Janeiro)  
*Professor*  
Department of Mechanical Engineering

Monica Feijo Naccache, PhD  
(Pontificial Catholic University of Rio de Janeiro)  
*Professor*  
Department of Mechanical Engineering

Sidnei Paciornik, PhD  
(Pontificial Catholic University of Rio de Janeiro)  
*Professor*  
Department of Materials Engineering

Luiz Antonio Pessan, PhD  
(Federal University of Sao Carlos)  
*Professor*  
Department of Materials Engineering

Cesar Liberato Petzhold, PhD  
(Federal University of Rio Grande do Sul)  
*Professor*  
Institute of Chemistry

Joao Henrique Zimnoc Dos Santos, PhD  
(Federal University of Rio Grande do Sul)  
*Professor*  
Institute of Chemistry

Paulo Henrique Schneider, PhD  
(Federal University of Rio Grande do Sul)  
*Professor*  
Institute of Chemistry

Henri Stephan Schrekker, PhD  
(Federal University of Rio Grande do Sul)  
*Professor*  
Institute of Chemistry

Argimiro Resende Secchi, PhD  
(Federal University of Rio de Janeiro)  
*Professor*  
COPPE-Chemical Engineering Program
Bluma Guenther Soares, PhD  
(Federal University of Rio Grande do Sul)  
Professor  
Institute of Chemistry  

Marcio Nele De Souza, PhD  
(Federal University of Rio de Janeiro)  
Professor  
Department of Chemical Engineering  

Frederico Wanderley Tavares, PhD  
(Federal University of Rio de Janeiro)  
Professor  
School of Chemistry and Program of Chemical Engineering of COPPE  

Roney Leon Thompson, PhD  
(Federal University of Rio de Janeiro)  
Professor  
Department of Mechanical Engineering  

Emeritus Faculty  
John Blackwell, PhD  
(University of Leeds, England)  
Leonard Case Jr. Professor  
Determination of the solid state structure and morphology of polymers. X-ray analysis of the structure of thermotropic copolymers, copolymides, polyurethanes, polysaccharides; supramolecular assemblies, fluoropolymers; molecular modeling of semi-crystalline and liquid crystalline polymers; rheological properties of polysaccharides and glycoproteins  

Alexander M. Jamieson, DPhil  
(Oxford University, England)  
Professor  
Quasielastic laser light scattering; relaxation and transport of macromolecules in solution and bulk; structure-function relationships of biological macromolecules  

David A. Schiraldi, Ph.D.  
(University of Oregon)  
Peter A. Asseff, Professor of Organic Chemistry Emeritus  
Composites, including Aerogel composites, structure-property relationships, transport phenomena and packaging materials, condensation polymers, bio-based polymer synthesis, polymer flammability and sustainable FR agents, polymer blends and complex polymer systems.  

Undergraduate Programs  
In 1970, the department introduced a program leading to the Bachelor of Science in Engineering degree with a major in Polymer Science and Engineering, which is designed to prepare the student both for employment in polymer-based industry and for graduate education in polymer science. The Case School of Engineering is proud that the polymer science and engineering program was the first such undergraduate program in the country to receive accreditation from the Engineering Council for Professional Development. The curriculum combines courses dealing with all aspects of polymer science and engineering with basic courses in chemistry, physics, mathematics, and biology, depending on the needs and interests of the student. The student chooses a sequence of technical electives, in consultation with a faculty advisor, allowing a degree of specialization in one particular area of interest, e.g., biomaterials, chemical engineering, biochemistry, or physics. In addition to required formal laboratory courses, students are encouraged to participate in the research activities of the department, both through part-time employment as student laboratory technicians and through the senior project requirement: a one or two semester project that involves the planning and performance of a research project.

Polymer science undergraduates are also strongly encouraged to seek summer employment in industrial laboratories during at least one of their three years with the department. In addition to the general undergraduate curriculum in Polymer Science and Engineering, the department offers two specialized programs which lead to the Bachelor of Science in Engineering with a major in Polymer Science and Engineering. The cooperative program contains all the course work required for full-time resident students plus one or two six-month cooperative sessions in polymer-based industry. The company is selected by the student in consultation with his or her advisor, depending on the available opportunities. The dual-degree program allows students to work simultaneously on two baccalaureate level degrees within the university. It generally takes five years to complete the course requirements for each department for the degree. The BS/MS program leads to the simultaneous completion of requirements for both the master's and bachelor's degrees. Students with a minimum GPA of 3.0 may apply for admission to this program in their junior year.

The Bachelor of Science in Engineering degree program with a major in Polymer Science and Engineering is accredited by the Engineering Accreditation Commission of ABET, http://www.abet.org.  

Program Educational Objectives  
This program will produce graduates who:  

1. Are competent, creative, and highly valued professionals in industry, academia, or government.  
2. Are flexible and adaptable in the workplace, possess the capacity to embrace new opportunities of emerging technologies, and embrace leadership and teamwork opportunities, all affording sustainable engineering careers.  
3. Continue their professional development by obtaining advanced degrees in Polymer Science and Engineering or other professional fields, as well as medicine, law, management, finance or public policy.  
4. Act with global, ethical, societal, ecological, and commercial awareness expected of practicing engineering professionals.  

Student Outcomes  
As preparation for achieving the above educational objectives, the Bachelor of Science in Engineering degree program with a major in Polymer Science and Engineering is designed so that students attain:  

• an ability to apply knowledge of mathematics, science, and engineering  
• an ability to design and conduct experiments, as well as to analyze and interpret data  
• an ability to design a system, component, or process to meet desired needs  
• an ability to function in multi-disciplinary teams  
• an ability to identify, formulate, and solve engineering problems
Bachelor of Science in Engineering
Required Courses: Major in Polymer Science and Engineering
In addition to engineering general education requirements (http://bulletin.case.edu/undergraduatesudies/csedegree/) and university general education requirements (http://bulletin.case.edu/undergraduatesudies/deegreeprograms/), the major requires the following courses:

**Traditional track**

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Units</th>
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<tbody>
<tr>
<td>EMAC 270</td>
<td>Introduction to Polymer Science and Engineering</td>
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</tr>
<tr>
<td>EMAC 276</td>
<td>Polymer Properties and Design</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 351</td>
<td>Physical Chemistry for Engineering</td>
<td>3</td>
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<tr>
<td>EMAC 352</td>
<td>Polymer Physics and Engineering</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 355</td>
<td>Polymer Analysis Laboratory</td>
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</tr>
<tr>
<td>EMAC 370</td>
<td>Polymer Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 372</td>
<td>Polymer Processing and Testing Laboratory</td>
<td>3</td>
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<tr>
<td>EMAC 375</td>
<td>Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology</td>
<td>3</td>
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<tr>
<td>EMAC 376</td>
<td>Polymer Engineering</td>
<td>3</td>
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<tr>
<td>EMAC 377</td>
<td>Polymer Processing</td>
<td>3</td>
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<tr>
<td>EMAC 378</td>
<td>Polymer Engineer Design Product</td>
<td>3</td>
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<tr>
<td>EMAC 398</td>
<td>Polymer Science and Engineering Project I</td>
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</tr>
<tr>
<td></td>
<td><strong>3 Technical Electives which can include a 3 or 6 credit sequence of</strong></td>
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<tr>
<td></td>
<td>EMAC 125/EMAC 325 Undergraduate Research</td>
<td>9</td>
</tr>
<tr>
<td></td>
<td>1 Natural Science Elective, chosen in consultation with the student's academic adviser.</td>
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**Biomaterials track**

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<td>EMAC 370</td>
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<td>EMAC 376</td>
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**Total Units** 45

Electives for Polymer Science Majors:

**Biomedical Engineering**

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<tr>
<td>EBME 201</td>
<td>Physiology-Biophysics I</td>
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<tr>
<td>&amp; EBME 202</td>
<td>Physiology-Biophysics II</td>
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<tr>
<td>EMAC 303</td>
<td>Structure of Biological Materials</td>
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**Chemical Engineering**

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<td>ECHE 260</td>
<td>Introduction to Chemical Systems</td>
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<tr>
<td>ECHE 361</td>
<td>Separation Processes</td>
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<tr>
<td>ECHE 364</td>
<td>Chemical Reaction Processes</td>
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</table>

**Bachelor of Science in Engineering**

Suggested Program of Study: Major in Polymer Science and Engineering

(standard track)

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu/).

**First Year**

<table>
<thead>
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<th>Course</th>
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<tr>
<td>Principles of Chemistry for Engineers (CHEM 111)**</td>
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<tr>
<td>Elementary Computer Programming (ENGR 131)**</td>
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<td>Calculus for Science and Engineering I (MATH 121)**</td>
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<tr>
<td>FSCC 100 Sages First Seminar*</td>
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<tr>
<td>PHED Physical Education Activities*</td>
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<tr>
<td>SAGES University Seminar I</td>
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<tr>
<td>Chemistry of Materials (ENGR 145)**</td>
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<td>Calculus for Science and Engineering II (MATH 122)**</td>
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<tr>
<td>General Physics I - Mechanics (PHYS 121)**</td>
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</table>
## Bachelor of Science in Engineering

### Suggested Program of Study: Major in Polymer Science and Engineering (biomaterials track)

The following is a suggested program of study. Current students should always consult their advisers and their individual graduation requirement plans as tracked in SIS (http://sis.case.edu/).

#### First Year

<table>
<thead>
<tr>
<th>Units</th>
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<th>Spring</th>
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<tbody>
<tr>
<td>Breadth elective **</td>
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<tr>
<td>Principles of Chemistry for Engineers (CHEM 111) **</td>
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<td>Elementary Computer Programming (ENGR 131) **</td>
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<td>PHED Physical Education Activities *</td>
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<td>Year Total:</td>
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#### Second Year

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<tr>
<td>Polymer Chemistry (EMAC 370)</td>
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<tr>
<td>Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology (EMAC 375)</td>
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<tr>
<td>Polymer Processing (EMAC 377)</td>
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<tr>
<td>Polymer Science and Engineering Project I (EMAC 398) ((SAGES Capstone Course))</td>
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<tr>
<td>Open elective</td>
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#### Third Year

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<tbody>
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<td>3</td>
<td></td>
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<tr>
<td>Polymer Processing and Testing Laboratory (EMAC 372)</td>
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<td></td>
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#### Fourth Year

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<th>Units</th>
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<th>Spring</th>
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<tbody>
<tr>
<td>Introduction to Circuits and Instrumentation (ENGR 210) **</td>
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<td></td>
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<tr>
<td>Polymer Chemistry (EMAC 370)</td>
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<td></td>
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<tr>
<td>Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology (EMAC 375)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Polymer Processing (EMAC 377)</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Polymer Science and Engineering Project I (EMAC 398) ((SAGES Capstone Course))</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Open elective</td>
<td>3</td>
<td></td>
</tr>
<tr>
<td>Year Total:</td>
<td>18</td>
<td>15</td>
</tr>
</tbody>
</table>

**University general education requirement

** Engineering general education requirement

Approved Natural Science electives:
- PHYS 221 Introduction to Modern Physics
- STAT 312 Basic Statistics for Engineering and Science
- PHYS 349 Methods of Mathematical Physics I
- BIOL 307 Introduction to Biochemistry: From Molecules To Medical Science

EMAC 325 may be taken as a technical elective. Students choosing the polymer major in the freshman year are encouraged to register for EMAC 125 (https://sis.case.edu/pisp/P90SCWR/?cmd=login&languageCd=ENG&l anguageCd=ENG) (1 credit), which may be used as a technical elective provided the student also completes EMAC 325 (https://sis.case.edu/pisp/P90SCWR/?cmd=login&languageCd=ENG) for at least 2 credits.

Technical sequence must be approved by department advisor.

Preparation for the polymer science project should commence in the previous semester.
Calculus for Science and Engineering III (MATH 223)** 3
General Physics II - Electricity and Magnetism (PHYS 122)** 4
Breadth elective ** 3
Physiology-Biophysics II (EBME 202)d 3
Polymer Properties and Design (EMAC 276) (SAGES Departmental Seminar) 3
Statics and Strength of Materials (ENGR 200)** 3
Elementary Differential Equations (MATH 224)** 3
Year Total: 16 15

Third Year

Breadth elective ** 3
Introductory Organic Chemistry I (CHEM 223)d 3
Chemical Laboratory Methods for Engineers (CHEM 290) 3
Introduction to Biomedical Materials (EBME 306) 3
Physical Chemistry for Engineering (EMAC 351) 3
Technical Elective I 3
Natural Science elective c 3
Introductory Organic Chemistry II (CHEM 224)d 3
Polymer Engineering (EMAC 376) 3
Structure of Biological Materials (EMAC 303) 3
Polymer Analysis Laboratory (EMAC 355) 3
Year Total: 15 18

Fourth Year

Breadth elective ** 3
Introduction to Circuits and Instrumentation (ENGR 210)** 4
Polymer Chemistry (EMAC 370) 3
Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology (EMAC 375) 3
Polymer Processing (EMAC 377) 3
Technical elective II 3
Polymer Engineer Design Product (EMAC 378) 3
Polymer Science and Engineering Project I (EMAC 398) (SAGES Capstone Course)g 3
Professional Communication for Engineers (ENGL 398) & Professional Communication for Engineers (ENGR 398)** 3
Technical elective IIIf 3
Open elective 3
Year Total: 19 15

Total Units in Sequence: 131

Hours required for graduation: 128

- University general education requirement
- Engineering general education requirement

Approved Natural Science electives:
- BIOL 214 Genes, Evolution and Ecology (d);
- BIOL 215 Cells and Proteins (d);
- BIOL 307 Introduction to Biochemistry: From Molecules To Medical Science (d);
- BIOL 362 Principles of Developmental Biology

Suggested for pre-med students

EMAC 355 Polymer Analysis Laboratory is strongly recommended.

At least 3 of the 4 Technical Electives have to be taken from:
- EBME 316 Biomaterials for Drug Delivery;
- EBME 325 Introduction to Tissue Engineering;
- EBME 350 Quantitative Molecular, Cellular and Tissue Bioengineering;
- EBME 426 Nanomedicine;
- EMAC 471 Polymers in Medicine / EBME 406 Polymers in Medicine;
- a three-credit research sequence of EMAC 125 Freshman Research on Polymers and EMAC 325 Undergraduate Research in Polymer Science
- EMAC 372 Polymer Processing and Testing Laboratory (offered in the spring semester of the fourth year)
- Other technical electives, as approved by the student’s academic advisor

Preparation for the polymer science project should commence in the previous semester.

Co-op and Internship Programs

Opportunities are available for students to alternate studies with work in industry or government as a co-op student, which involves paid full-time employment over seven months (one semester and one summer). Students may work in one or two co-ops, beginning in the third year of study. Co-ops provide students the opportunity to gain valuable hands-on experience in their field by completing a significant engineering project while receiving professional mentoring. During a co-op placement, students do not pay tuition but maintain their full-time student status while earning a salary. Learn more at http://engineering.case.edu/coop/. Alternatively or additionally, students may obtain employment as summer interns.

Five-Year Combined BS/MS Program

This program offers outstanding undergraduate students the opportunity to obtain an MS degree, with a thesis, in one additional year of study beyond the BS degree (normally, it takes 2 years beyond the BS to earn an MS degree). In this program, an undergraduate student can take up to 9 credit hours that simultaneously satisfy undergraduate and graduate requirements. If the BS part of the BS/MS is in Polymer Science & Engineering, then participating students generally will not take the standard EMAC 401-405 sequence; the additional course work will be taken as electives in this case. Students in this program typically produce a senior thesis during the fall of their fourth year. They then start their research leading to the MS thesis in the spring semester of that year, culminating in a thesis defense spring semester of year five.

Application for admission to the five year BS / MS program is made after completion of five semesters of course work. Minimum requirements are a 3.2 grade point average and the recommendation of a faculty member of the department. Review the Office of Undergraduate Studies BS/MS program requirements here (http://bulletin.case.edu/undergraduatestudies/gradprofessional/accelerationtowardgraduatedegreetext).
Year five plan

Fifth Year

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
<th>Fall</th>
<th>Spring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical Elective 1</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thesis M.S. (EMAC 651)</td>
<td>6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Elective 2</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Technical Elective 3</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thesis M.S. (EMAC 651)</td>
<td>3</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thesis defense (typically by mid-March)</td>
<td></td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>Year Total:</td>
<td></td>
<td>9</td>
<td>9</td>
</tr>
</tbody>
</table>

Total Units in Sequence: 18

Note: A number of 2 credit hour electives are offered each year by the Macro Department, so students may elect to take a sequence of four electives, totaling at least 9 credit hours, in addition to the required 9 hours of EMAC 651 Thesis M.S.

Minor in Polymer Science and Engineering

The minor in Polymer Science and Engineering consists of five courses from the list below (special arrangements can be made to include appropriate EMAC graduate courses as well).

Required Courses

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAC 270 Introduction to Polymer Science and Engineering</td>
<td>6</td>
</tr>
<tr>
<td>EMAC 276 Polymer Properties and Design</td>
<td>9</td>
</tr>
</tbody>
</table>

Choose any three of the remaining courses listed below

<table>
<thead>
<tr>
<th>Course</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAC 351 Physical Chemistry for Engineering</td>
<td>6</td>
</tr>
<tr>
<td>EMAC 355 Polymer Analysis Laboratory</td>
<td>6</td>
</tr>
<tr>
<td>EMAC 370 Polymer Chemistry</td>
<td>6</td>
</tr>
<tr>
<td>EMAC 372 Polymer Processing and Testing</td>
<td>6</td>
</tr>
<tr>
<td>EMAC 375 Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology</td>
<td>6</td>
</tr>
<tr>
<td>EMAC 376 Polymer Engineering</td>
<td>6</td>
</tr>
<tr>
<td>EMAC 377 Polymer Processing</td>
<td>6</td>
</tr>
<tr>
<td>EMAC 378 Polymer Engineer Design Product</td>
<td>6</td>
</tr>
</tbody>
</table>

Total Units 15

Graduate Programs

Courses leading to the Master of Science (MS) and Doctor of Philosophy (PhD) degrees in macromolecular science are offered within the Case School of Engineering. They are designed to increase the student's knowledge of macromolecular science and of his/her own basic area of scientific interest, with application to specific polymer research problems. Research programs derive particular benefit from close cooperation with graduate programs in chemistry, physics, materials science, chemical engineering, biological sciences, and other engineering areas. The interdisciplinary academic structure allows the faculty to fit the individual program to the student's background and career plans. Basic and advanced courses are offered in polymer synthesis, physical chemistry, physics, biopolymers, and applied polymer science and engineering. A laboratory course in polymer characterization instructs students in the use of modern experimental techniques and equipment. Graduate students are also encouraged to take advanced course work in polymer solid state physics, physical chemistry, synthesis, rheology, and polymer processing.

Master of Science

Master's Thesis-Focused Track

The minimum requirement to complete a master's degree under the Thesis-Focused Track is 30 hours. Of the 30 hours, at least 18 hours must be coursework, and 9 hours must be EMAC 651 Thesis M.S. At least 18 semester hours of coursework, including thesis, must be at the 400 level or higher.

All Thesis-Focused MS students must take 6 credits of departmental fundamentals courses including the lab component. Please note: Once a student begins registration of EMAC 651 Thesis M.S., the student must register for at least one credit hour of this course every semester until graduation. The normal residency period for an MS degree is 2 years.

Elective and core courses can be taken via Distance Learning or by transfer (transfers need to be approved by the chair of the department and dean of graduate studies; core courses also need instructors’ approval).

MS students will generally be required to take the core courses:

- EMAC 401 Polymer Foundation Course I: Organic Chemistry
- EMAC 402 Polymer Foundation Course II: Physical Chemistry
- EMAC 403 Polymer Foundation Course III: Physics
- EMAC 404 Polymer Foundation Course IV: Engineering

Plus an additional 6 credit hours of coursework for Thesis-Focused courses to be approved by their advisor.

For completion of a master's degree in the Thesis-Focused Track, an oral examination (defense) of the master's thesis is required. The examination is conducted by a committee of three university faculty members. The candidate's thesis advisor usually serves as the chair of the examining committee. The chair of the department or the curricular program faculty appoints members of the committee. The examining committee must agree unanimously that the candidate has passed the thesis examination.

Master's Project-Focused Track

The master's Project-Focused Track is available for individuals who live out of state or are working full-time. A research report and oral examination are required before graduation. This option requires 30 total credit hours; categorized by the following:

1. 3-6 cr. hrs. need to be project credit (independent study) which needs to be approved by advisor
2. 21-24 course credits (of which 9 must be based in Macromolecular Science); and
3. 6 core course credits

Each candidate for the master's degree under Project-Focused Track must satisfactorily pass a comprehensive examination, which is administered by the department or curricular program committee. The examination may be written or oral or both. A student must be registered during the semester in which any part of the comprehensive examination is taken. If not registered for other courses, the student will be required...
to register for one semester hour of EXAM 600 Master’s Comprehensive Exam, before taking the examination.

Elective and core courses can be taken via Distance Learning or by transfer (transfers need to be approved by the chair of the department and dean of graduate studies; core courses also need instructors’ approval).

MS students will generally be required to take the core courses:

EMAC 401 Polymer Foundation Course I: Organic Chemistry
EMAC 402 Polymer Foundation Course II: Physical Chemistry
EMAC 403 Polymer Foundation Course III: Physics
EMAC 404 Polymer Foundation Course IV: Engineering

Plus an additional 15 credit hours of coursework for Project-Focused courses to be approved by their advisor.

Master’s Course-Focused Track
The Course-Focused MS degree program requirements consist of the completion of 30 hours of approved coursework at the 400 level or higher, satisfactory completion of the culminating course-focused experience, i.e. passing the course ENGR 600 with requirements defined by the student’s curricular program, and additional requirements as specified by the program. Students should consult with their academic advisor and/or department to determine the detailed requirements within this framework.

Master of Science in Engineering with Specialization
Advanced Films and Packaging Systems
The Department of Macromolecular Science and Engineering at Case Western Reserve University offers a Master’s Degree track in Advanced Films and Packaging Systems. This program is designed to be completed in one year but can be spread out over multiple years. Options for either a thesis-based or a course-based Master’s are available.

Through a 30 credit hour curriculum, students explore and learn how to apply the fundamental principles of macromolecular science and engineering toward emerging challenges and opportunities in the utilization of plastics in films and packaging. The department offers a unique intersection of deep expertise polymer synthesis, structure-property relationships, and processing which can be applied to benefit an industry with a global economic impact of at least $1 trillion annually.

Core Course Requirements (9 credits):

EMAC 436 Polymers in Advanced Packaging Systems 2
EMAC 437 Advanced Polymeric Films 2
EMAC 438 Packaging Design and Innovation 3
EMAC 450 The Business of Polymers 2

Degree Options
The Fire Science and Engineering master’s degree track comprises 30 credit hours, which may be all coursework or include an MS thesis (9 credit hours) or a project (3 to 6 credit hours). Students can choose to
receive a Master of Science in Macromolecular Science and Engineering with a specialization in Fire Science and Engineering, or a Master of Science in Mechanical Engineering with a specialization in Fire Science and Engineering.

All students will take six core fire protection engineering courses. Other courses can be chosen from the elective track for macromolecular science and engineering or mechanical engineering. The materials track focuses on polymer chemistry and materials, and the chemistry of flammability and fire suppression. The mechanical track follows a traditional mechanical engineering/combustion approach to fire protection and suppression, but with specialization classes in polymers.

The track can be finished in one year or in multiple years. Students have the option of completing a thesis or research project at their employers' laboratories with Case Western Reserve faculty members as co-advisors.

For additional information, please contact:
Gary Wnek, Chair of the Department of Macromolecular Science and Engineering
Ya-Ting Liao, Assistant Professor in the Department of Mechanical and Aerospace Engineering

Academic Calendar

This fire protection engineering degree is offered over three semesters: 12 credits in the fall semester; 12 credits in the spring semester; and 6 credits in the summer. See the university's academic calendar (http://www.case.edu/registrar/calendar.html).

How to Apply

Application to the Fire Science and Engineering program is handled through the university's School of Graduate Studies. Students will need to know whether they wish to apply for the MS in Macromolecular Science and Engineering or the MS in Mechanical Engineering.

Students interested in applying to the Fire Science and Engineering program should already have a bachelor's degree in Chemistry, Chemical Engineering, Mechanical Engineering or Materials Science & Engineering and have taken the GRE. Additional application requirements include a statement of objectives, academic transcripts, and three letters of recommendation. International students will also need to take the Test of English as a Foreign Language (TOEFL). Read more about the university's full application procedure requirements here (http://gradstudies.case.edu/prospect/admissions/apply.html).

When you are ready to apply, electronic applications can be submitted here (https://app.applyyourself.com/AYApplicantLogin/ApplicantConnectLogin.asp?id=casegrad).

PhD Programs

The PhD program consists of 36 hours of coursework, including the departmental core courses and 18 credit hours of PhD thesis (EMAC 701 Dissertation Ph.D.) are required for the PhD degree, in addition to passing the research qualifying exam (oral proposal) and the written qualifying exam.

Of the coursework credit requirements, the core courses are designated as "depth" courses (12 credits). In addition, all students will take a minimum of two breadth courses in basic science and/or other departments in the School of Engineering (for a total of six credits). The remaining breadth requirements (up to 18 credits) are satisfied by course modules taken in Macromolecular Science and Engineering.

Each doctoral student is responsible for becoming sufficiently familiar with the research interests of the department or program faculty to choose in a timely manner a faculty member who will serve as the student's research advisor. The research advisor is expected to provide mentorship in research conception, methods, performance, and ethics, as well as focus on development of the student's professional communication skills, building professional contacts in the field, and fostering the professional behavior standard of the field and research in general.

The research advisor also assists with the selection of three other faculty to serve as the required additional members of the dissertation advisory committee. This committee must be formed within the second semester following admission. Throughout the development and completion of the dissertation, these members are expected to provide constructive criticism and helpful ideas generated by the research problem from the viewpoint of their particular expertise. Each member will make an assessment of the originality of the dissertation, its value, the contribution it makes and the clarity with which concepts are communicated, especially to a person outside the field.

The doctoral student is expected to arrange meetings and maintain periodic contact with each committee member. A meeting of the full committee for the purpose of assessing the student's progress should occur at least once a year until the completion of the dissertation.

For students entering the PhD program with an MS degree, 18, instead of 36 credit hours, of coursework is required. Other requirements for a PhD remain the same as described above. Normally students should orient their training around their main area of interest/expertise and in relation to their research program. For those enrolled in the MD/PhD degree program, all 18 course credits for breadth and depth courses must be taken within the Medical School Program.

The core courses designated as depth courses are:

<table>
<thead>
<tr>
<th>Course</th>
<th>Title</th>
<th>Credits</th>
</tr>
</thead>
<tbody>
<tr>
<td>EMAC 401</td>
<td>Polymer Foundation Course I: Organic Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 402</td>
<td>Polymer Foundation Course II: Physical Chemistry</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 403</td>
<td>Polymer Foundation Course III: Physics</td>
<td>3</td>
</tr>
<tr>
<td>EMAC 404</td>
<td>Polymer Foundation Course IV: Engineering</td>
<td>3</td>
</tr>
</tbody>
</table>

Students are required to take all four depth courses (12 credits), but on the approval of the instructor, can be excused from one or more of the courses if the relevant course content is not satisfied by a course taken in prior undergraduate or graduate degrees. However, the excused credits must be fulfilled by taking additional breadth courses. NOTE: While EMAC 401 Polymer Foundation Course I: Organic Chemistry and EMAC 402 Polymer Foundation Course II: Physical Chemistry, and EMAC 404 Polymer Foundation Course IV: Engineering are offered at the same time in the Fall and Spring semesters, respectively, students can still sign up for both courses, since one is offered in the first half and the other in the second half of the semester.

Two courses in basic science and/or engineering are required. These courses can be taken in other departments of the School of Engineering.
or the departments of Mathematics, Biology, Biochemistry, Chemistry, or Physics as approved by the advisor.

As part of the course requirements, all students are required to register for EMAC 677 Colloquium in Macromolecular Science and Engineering (the Friday departmental seminars) which will be graded with either “Pass” or “No Pass.”

Students who have taken EMAC 370 Polymer Chemistry and EMAC 376 Polymer Engineering as undergraduates can use these courses to fulfill one or more of the depth requirements in the Department of Macromolecular Science and Engineering for the MS and PhD degree. However, the credits for this course cannot be applied towards the course credit requirements for the graduate degree. Exceptions are possible for the combined BS/MS program.

**Graduate Program Rules**

Graduates entering the Department of Macromolecular Science and Engineering are subject to the academic rules of the University, of the School of Engineering, and of the Department. Consult the Graduate Student Handbook (http://gradstudies.case.edu/).

A short abstract of important points include:

1. GPA requirements are described below in the Departmental Rules.
2. A student receiving a “U” in a course is automatically placed on probation and must remove him/herself from probation within one year (usually by repeating the course). If a course is repeated, both original and revised grades will count in the grade point average.
3. Some students are admitted on a probationary basis and must achieve a 3.0 GPA after two semesters to remain in good standing (this is a rule of the Engineering School).
4. Students entering the graduate program for a PhD will need to fill out the Academic Program by the end of their second semester.
5. All students are required to serve as teaching assistants. Responsibilities as a TA include serving as an instructor, lab assistant, recitation leader, grader, or tutor in an undergraduate course. After fulfilling the required teaching assistant program, UNIV 400, students will make sure that three teaching courses (400T, 500T, and 600T) are listed on their Academic Program. Completion of this teaching requirement will be monitored by Graduate Studies and is required in order to graduate.

**Engineering School Rules**

Most of these rules are incorporated in the number and type of courses required by the Department. However, Case School of Engineering PhD students are required to 1) maintain full-time status as a PhD bound student; 2) maintain a grade point average of 3.2 or above; and 3) continue making satisfactory academic progress as certified by their advisor.

**Departmental Rules**

1. Students in the PhD program receiving a GPA below 2.50 in any two consecutive semesters will be asked to terminate their graduate study program.
2. The GPA requirement established by the university at various stages of the graduate program shall exclude MS or PhD thesis credits which will be graded “S” or “U” until a final grade is given at the end of the program. Hence a student must maintain a minimum GPA of 3.0 (for an MS) OR a 3.0 (for a PhD) in coursework. (As mentioned above, Case School of Engineering PhD students must maintain a GPA of 3.2 or above.)

3. Thesis-Focused Track MS students must give a departmental seminar (as part of the student lecture series).
4. Project-Focused Track MS degrees are limited to non-fellowship students.

5. Coursework may be transferred from another university, subject to Graduate Committee approval if:
   - the courses duplicate requirements of the department;
   - the courses were in excess of the undergraduate degree requirements; or
   - the courses were taken in a graduate program elsewhere;
   - a grade of B or better was achieved in those courses;
   - a petition is made to and approved by the Graduate Committee of the Department
   - the transferred grades will not count in the GPA at CWRU

6. The Department reserves the right to withhold financial support to a student if that student takes an undue amount of time in completing his/her MS or PhD requirements (normally no longer than 3 years for MS and 5 years after initial registration of EMAC 701 Dissertation Ph.D.).

7. A PhD student must pass the written Qualifying Exam within 18 months after enrollment with an MS degree into the PhD program. A PhD student must pass the written Qualifying Exam within 24 months after enrollment with a BS degree into the PhD program. A student only has two chances to pass the Qualifying Exam. Students will be asked to answer 4 mandatory questions – one from each of the following five areas:
   - Polymer Synthesis
   - Polymer Physical Chemistry
   - Polymer Physics
   - Applied Polymer Science
   - Seminars (from the previous year)

Two elective questions will be chosen from a number of questions from all elective courses offered in the Department. NOTE: The Qualifying Exam is given twice per year respectively on the first Friday at the beginning and the first Friday after the end of the Spring semester. For PhD students enrolled in a Spring semester, those with MS must pass the Qualifying Exam at the end of his/her second Spring semester, and those with BS must pass it at the beginning of his/her third Spring semester.

8. The Research Qualifying Exam (RQE) is designed to test the student's knowledge of the chosen field as well as his/her originality and ability to perform high quality, independent research. It consists of a written research proposal and an oral defense. All PhD students who hold an MS degree must pass the RQE within 2 years of enrolling in the PhD program, while students with a BS degree must do so within 2.5 years. Successful passing of the Written Qualifying Exam (not to be confused with the written portion of this RQE) is a prerequisite to taking the RQE. Students have two chances to pass the RQE and no student will be allowed to continue on to a PhD degree if he/she has not successfully taken it. A conditional pass with major revision (see below) requires modification to the
written or oral portion, at the examination committee’s discretion, within ten business days and following guidelines by the examination committee. A second exam, if required due to failure of the first exam, must be taken within six months of the first exam with at least one examination committee member remaining the same. Passing the exam constitutes advancement to candidacy and is required for enrolling in EMAC 701 Dissertation Ph.D.

9. At least three (3) weeks prior to the RQE oral defense, the student will submit to the graduate chairperson a research proposal title with a one-paragraph synopsis of the research problem and approach, along with suggestions for two members (i) and (ii), below) of the three member examining committee. The examination committee will consist of three faculty members: (i) a member (or intended member) of the student’s Thesis Advisory Committee, (ii) an expert in the research proposal area and (iii) a faculty member selected systematically and in a neutral manner by the Graduate Committee. The student’s primary thesis advisor or co-advisors is/are excluded from the examining committee. Upon establishing the examining committee, the student will arrange with the committee for the date, time, and location of the RQE. The student will then distribute the written research proposal to the examining committee five full business days before the defense. It should be no less than 15 and no more than 20 pages of double-spaced text with 1” margins on all sides. No more than 5 pages can be devoted to the proposal introduction or background. Figures, tables, and schemes should not exceed five pages in total. Literature citations are in addition to this page count. The oral presentation will be chaired by a designated chairperson from the examining committee. It should contain only limited background material, focusing primarily on execution of the proposed research. The oral presentation should last 20-30 minutes, with questions from faculty being for clarification only. Following the presentation, the examining committee will ask questions for the student to answer concerning the proposal. On the basis of the written proposal and oral defense (presentation and question responses), the faculty will then confer and tender a decision of pass, conditional pass with major revision, or fail, immediately. The decision will be communicated to the student and graduate chairperson in writing within one business day.

10. All PhD students are required to fulfill their teaching requirement by registering for the three teaching courses, 400T, 500T, and 600T that will be posted to the departmental roster each semester. Completion of the teaching requirement will be monitored by Graduate Studies, and these three teaching courses must appear both on the Program of Study form and the student’s transcript.

11. It is expected that all students will present the results of their research in a Departmental Seminar. This is mandatory for students enrolled in the PhD program. Attendance and registration for these seminars EMAC 677 Colloquium in Macromolecular Science and Engineering. Colloquium Seminars are also mandatory.

12. The department requires the equivalent of six credit hours of departmental assistance. This requirement takes the form of grading, laboratory assistance and/or general departmental duties and is designed to utilize no more than three hours/week of a student’s time. The departmental service requirement must be completed within the first two semesters of study. However, the departmental service requirement form must be turned in at the end of each semester until the obligation is met.

13. Vacation Policy. Graduate students in the department who receive fellowship support for 12 months are normally entitled to two weeks vacation plus national holidays. Alternative arrangements may be made with the student’s advisor, giving ample advance notice. In certain situations, it is possible to take a leave of absence without financial support.

14. Prior to graduation, a student is required to clean out his/her laboratory space including removal of waste solvents and hazardous material.

15. Failure to comply with all of the above course requirements may result in termination or delay in graduation.

Facilities

The Kent Hale Smith Science and Engineering Building houses the Department of Macromolecular Science. The building was built in 1993, and specifically designed to meet the specific needs of polymer research. The facility consists of five floors, a basement. The laboratories for chemical synthesis are located principally on the top floor, the molecular and materials characterization laboratories on the middle floors, and the major engineering equipment on the ground floor, while the NMR, MALDI-TOF, and TA-Instruments. Thermal Characterization instrumentation are located in the basement. Modern, computer-interfaced classrooms are installed on the ground floor. Additional instrumentation available includes Small and Wide-Angle X-ray diffractometers; scanning electron microscopy; a complete range of molecular spectroscopic equipment including FTIR, Laser Raman, and high resolution solution and solid-state NMR (including imaging), as well as Raman and FTIR microscopes; and dynamic light scattering spectroscopy. There are also facilities for polymer characterization (molecular weight distribution), optical microscopy, solution and bulk rheology, scanning calorimetry, and for testing and evaluating the mechanical properties of materials. A newly built-out processing lab provides the complete suite of Thermo-Fisher batch, single- and twin-screw mixing and extrusion equipment, as well as that manufacturer’s state of the art rheometers. The C. Richard Newpher polymer processing laboratory includes a high temperature Rheometrics RMS-800 dynamic mechanical spectrometer, a Bomem DA-3 FTIR with FT-Raman capabilities, a compression molding machine, a Brabender plasticorder, a high speed Instron testing machine, and a vibrating sample magnetometer. The Charles E. Reed ’34 Laboratory is concerned with the mechanical analysis of polymeric materials. The major testing is done by Instron Universal testing instruments including an Instron model 1123 with numerous accessories such as an environmental chamber for high or low temperature experiments. Additional mechanical testing of fibers, films and injection-molded (Boy model 22-S) are provided by MTS universal testers which are used for both research and undergraduate teaching laboratory classes. The NSF Center for Layered Polymeric Systems (CLiPS) has its central facility within the department, with three cutting-edge multilayer extrusion systems as its centerpiece. CLiPS also operates a Bruckner KARO IV biaxial stretching unit, which allows controlled biaxial stretching of polymer films, and an Atomic Force Microscope which probes the morphological and mechanical properties of materials at the nanoscale. The Molecular Modeling Center provides access to various software packages for the rheological and molecular modeling of polymers.
Courses

EMAC 125. Freshman Research on Polymers. 1 Unit.
Freshman research in polymer chemistry, engineering, and physics. Students will be placed in active research groups and will participate in real research projects under the supervision of graduate students and faculty mentors.

EMAC 270. Introduction to Polymer Science and Engineering. 3 Units.

EMAC 276. Polymer Properties and Design. 3 Units.
The course reviews chemical and physical structures of a wide range of applications for synthetic and natural polymers, and addresses "Which polymer do we choose for a specific application and why?" We examine the polymer properties, the way that these depend on the chemical and physical structures, and reviews how they are processed. We aim to understand the advantages and disadvantages of the different chemical options and why the actual polymers that are used commercially are the best available in terms of properties, processibility and cost. The requirements include two written assignments and one oral presentation. Prereq: ENGR 145 and EMAC 270.

EMAC 303. Structure of Biological Materials. 3 Units.
Structure of proteins, nucleic acids, connective tissue and bone, from molecular to microscopic levels. An introduction to bioengineering biological materials and biomimetic materials, and an understanding of how different instruments may be used for imaging, identification and characterization of biological materials. Recommended preparation: EMAC 270. Offered as: EBME 303 and EMAC 303. Prereq: EBME 201, EBME 202, and EBME 306.

EMAC 325. Undergraduate Research in Polymer Science. 1 - 3 Units.
Undergraduate laboratory research in polymer chemistry/physics/ engineering. Students will undertake an independent research project, working under the mentoring of both a graduate student and a faculty member. A mid-term written progress report is required. A written report and oral presentation will be made at the end of the semester. Can be taken for 1-3 credits per semester, up to a total of 6 credit hours. Students are expected to spend approximately 5 hours/week in the laboratory per credit registered each semester. Recommended preparation: Sophomore/ Junior standing and consent of instructor.

EMAC 351. Physical Chemistry for Engineering. 3 Units.
Principles of physical chemistry and their application to systems involving physical and chemical transformations. The nature of physical chemistry, properties of gases, overview of the laws of thermodynamics, thermochemistry, solutions, phases and chemical equilibrium, kinetics of chemical reaction, solutions of electrolytes and introduction to quantum mechanics, atomic structure and molecular statistics. Prereq: ENGR 145.

EMAC 352. Polymer Physics and Engineering. 3 Units.
Single chain statistics and thermodynamics of dilute polymer solutions (single chain statistics, Flory-Kringbaum theory, vapor pressure and osmotic pressure, light, small angle X-Ray, and small-angle neutron scattering), solid state properties of polymers (polymer viscoelasticity (time-temperature superposition; rubber thermodynamics and statistics), glasses and related mechanical properties (fracture mechanism), crystals and liquid crystals; structure property relationship, polymer blends, block copolymers and composites, transport phenomena (conversation of mass, momentum and energy, differential forms, integral forms, momentum transport, laminar and turbulent flow, Navier-Stokes equation, mass transport, diffusion, Fick's law) and transport phenomena of polymer solutions (intrinsic viscosity, sedimentation and diffusion, dynamic light scattering, polyelectrolytes and block copolymers in solution, size exclusion chromatography). Prereq: EMAC 351

EMAC 353. Foundations of Scattering. 3 Units.
Introduction to the fundamentals of using scattering techniques to characterize the structure and dynamics of soft matter and its interfaces, with an emphasis on X-ray and neutron techniques. Topics covered include a mechanistic description of scattering processes, diffraction, small-angle scattering, reflectometry, and quasi-elastic scattering applied to polymers, proteins, gels/networks, nanoparticles, and other soft materials. Offered as EMAC 353 and EMAC 453. Prereq: EMAC 351 and EMAC 352.

EMAC 355. Polymer Analysis Laboratory. 3 Units.
Experimental techniques in polymer synthesis and characterization. Synthesis by a variety of polymerization mechanisms. Quantitative investigation of polymer structure by spectroscopy, diffraction and microscopy. Molecular weight determination. Physical properties. Prereq: EMAC 276 and (CHEM 290 or CHEM 322).

EMAC 370. Polymer Chemistry. 3 Units.
The fundamentals of organic chemistry of polymer synthesis, suitable for laboratory and industrial polymer production. Prereq: EMAC 270 and (CHEM 224 or CHEM 324).

EMAC 372. Polymer Processing and Testing Laboratory. 3 Units.
Basic techniques for the rheological characterization of thermoplastic and thermoset resins; "hands-on" experience with the equipment used in polymer processing methods such as extrusion, injection molding, compression molding; techniques for mechanical characterization and basic principles of statistical quality control. Prereq: EMAC 377.

EMAC 375. Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology. 3 Units.
This course will involve the study of Rheology from the perspectives of rheological property measurement, phenomenological and molecular models, and applicability to polymer processing. In particular, students will be introduced to 1) General concepts of Rheology and Newtonian Fluid Mechanics, 2) Standard flows and material functions; 3) The role of Rheology as a structural characterization tool, with an emphasis on polymeric systems; 4) Experimental methods in Rheology with quantitative descriptions of associated flows and data analyses; 5) Viscoelasticity and Non-Newtonian Fluid Mechanics, including the application of models, both phenomenological and molecular, to the prediction of rheological behavior and extraction of model parameters from real data sets; and 6) The relevance of rheological behavior of different systems to practical processing schemes, particularly with respect to plastics manufacturing. Offered as EMAC 375 and EMAC 475. Prereq: ENGR 225 or EMAC 404.
EMAC 376. Polymer Engineering. 3 Units.

EMAC 377. Polymer Processing. 3 Units.
Application of the principles of fluid mechanics, heat transfer and mass transfer to problems in polymer processing; elementary steps in polymer processing (handling of particulate solids, melting, pressurization and pumping, mixing); principles and procedures for extrusion, injection molding, reaction injection molding, secondary shaping. Prereq: EMAC 352 or ENGR 225.

EMAC 378. Polymer Engineer Design Product. 3 Units.
Uses material taught in previous and concurrent courses in an integrated fashion to solve polymer product design problems. Practicability, external requirements, economics, thermal/mechanical properties, processing and fabrication issues, decision making with uncertainty, and proposal and report preparation are all stressed. Several small exercises and one comprehensive process design project will be carried out by class members. Offered as EMAC 378 and EMAC 478. Counts as SAGES Senior Capstone.

EMAC 379. Advanced Polymer Engineering. 2 Units.
This Advanced Polymer Engineering course will focus on the ultimate engineering properties for polymers, including fracture mechanics, electrical, and optical properties of polymers. For polymer fracture mechanics, deformation and fracture behavior of polymers will be introduced. The electrical properties include both insulation and conduction/semiconduction properties for polymers. In the optical property section, we will introduce polymer photonics and polymers in liquid crystal displays. The goal of the course is to help students achieve fundamental understanding of advanced polymer properties. EMAC 479 students will do an additional project design. Offered as EMAC 379 and EMAC 479. Prereq: EMAC 376.

EMAC 396. Special Topics. 1 - 18 Units.
(Credit as arranged.)

EMAC 398. Polymer Science and Engineering Project I. 1 - 3 Units.
(Senior project). Research under the guidance of faculty. Requirements include periodic reporting of progress, plus a final oral presentation and written report. Repeatable up to 3 credit hours. When taken for 3 credits it may be spread over two successive semesters. Counts as SAGES Senior Capstone. Prereq: Senior Standing.

EMAC 399. Polymer Science and Engineering Project II. 1 - 9 Units.
(Senior project.) Research under the guidance of staff, culminating in thesis. Recommended preparation: Majors only and senior standing.

EMAC 400T. Graduate Teaching I. 0 Unit.
This course will engage the Ph.D. students in teaching experiences that will include non-contact (such as preparation and grading of homeworks and tests) and direct contact (leading recitations and monitoring laboratory works, lectures and office hours) activities. The teaching experience will be conducted under the supervision of the faculty. All Ph.D. students will be expected to perform direct contact teaching during the course sequence. The proposed teaching experiences for EMAC Ph.D. students are outlined below in association with undergraduate classes. The individual assignments will depend on the specialization of the students. The activities include grading, recitation, lab supervision and guest lecturing. Recommended preparation: Ph.D. student in Macromolecular Science.

EMAC 401. Polymer Foundation Course I: Organic Chemistry. 3 Units.
The class is an introduction to the synthesis and organic chemistry of macromolecules. The course introduces the most important polymerization reactions, focusing on their reaction mechanisms and kinetic aspects. Topics include free radical and ionic chain polymerization, condensation (step-growth) polymerization, ring-opening, insertion and controlled addition polymerization. There is no limit on the number of students for the class as a whole.

EMAC 402. Polymer Foundation Course II: Physical Chemistry. 3 Units.
This class is an introduction to the physical chemistry of polymers in solution. Topics include: polymer statistics: (microstructure, chain configuration, and chain dimensions), thermodynamics and transport properties of polymers in solution, methods for molecular weight determination, physical chemistry of water-soluble polymers, and characterization of polymer microstructure (IR and NMR). There is no limit on the number of students for the class as a whole.

EMAC 403. Polymer Foundation Course III: Physics. 3 Units.
This class is an introduction to the physics of polymers in the bulk amorphous and crystalline states. Topics include: structural and morphological analysis using X-ray diffraction, electron microscopy and atomic force microscopy, characterization of thermal transitions, viscoelastic behavior and rubber elasticity, and dynamic mechanical analysis. There is no limit on the number of students for the class as a whole.

EMAC 404. Polymer Foundation Course IV: Engineering. 3 Units.
This class is an introduction to the engineering and technology of polymeric materials. Topics include: additives, blends and composites, natural polymers and fibers, thermoplastics, elastomers, and thermosets, polymer degradation and stability, polymers in the environment, polymer rheology and polymer processing, and polymers for advanced technologies (membrane science, biomedical engineering, applications in electronics, photonic polymers). There is no limit on the number of students for the class as a whole.

EMAC 405. Polymer Characterization Laboratory. 3 Units.
Laboratory experience through synthesis and characterization of polymers. Synthesis via addition and condensation polymerization. Characterization methods include size exclusion chromatography, infrared and NMR spectroscopy. Solid samples are characterized by X-ray diffraction, electron microscopy, thermal analysis, and physical properties. Fluid samples are characterized by melt rheology. Prereq: EMAC 401, EMAC 402, EMAC 403 and EMAC 404.

EMAC 410. Polymers Plus Self - Assembly and Nanomaterials. 2 Units.
The course focuses on the concepts of supramolecular chemistry and self-assembly specifically as it applies to nano-polymeric systems. After dealing with many of the fundamental aspects of supramolecular chemistry the focus of the class deals with how to access/utilize nano-scale features using such processes, namely the ‘bottom-up’ approach to nanomaterials/systems. Areas which will be addressed include block copolymers, DNA assemblies, nanotubes and dendrimers. Prereq: EMAC 401 or EMAC 370.

EMAC 413. Polymers Plus Green Chemistry and Engineering. 2 Units.
This course focuses on green chemistry and engineering, particularly as it relates to polymers. Specific topics to be covered in this course will include green chemistry, catalysis, alternative solvents, green processing, renewable materials, and life cycle analysis. Case studies will be utilized to connect lecture topics to real-world examples. Prereq: EMAC 401 and EMAC 404.
EMAC 415. Polymers Plus Structure and Morphology. 2 Units.
This special topic focuses on polymer structure and morphology and their applications. Topics include solid-state physics of various polymeric materials, ranging from crystalline polymers to liquid crystalline polymers, and block copolymers. First, symmetry operation, space groups, reciprocal spaces are introduced. Examples of the crystalline structures of industrially important polymers and typical polymer crystalline morphology such as lamellar and spherulitic crystals are discussed. Defects in crystalline polymer is also an important issue that determines their physical properties. Second, typical phase structure and transitions of liquid crystals and liquid crystalline polymers are introduced, including both thermotropic and lyotropic liquid crystals. Finally, nanostructure and morphology of block copolymers are discussed. Prereq: EMAC 402 and EMAC 403.

EMAC 422. Polymers Plus Microscopy. 2 Units.
This course focuses on application of microscopy techniques to the analysis of the microstructure of polymeric materials. Specifically, atomic force microscopy, transmission and scanning electron microscopy, and optical microscopy will be discussed. Practical aspects of these techniques will be applied to a variety of systems, including block copolymers, nanocomposites, LC polymers, and multi-layered films. Prereq: EMAC 403.

EMAC 426. Biopolymers: Structure, Synthesis, and Application in Medicine. 2 Units.
An introduction to biomacromolecules including DNA, RNA, and proteins. The course will deal with the synthesis and manipulation of biological and synthetic macromolecules as it applies to topics in modern medicine. Topics covered will include nanoparticle gene and drug delivery systems, polymer hydrogels, polymer imaging agents, and protein-polymer conjugates. The purpose of this course is to provide a survey of important areas in medicine where a polymer chemist/engineer can intervene to make a meaningful contribution. Prereq: CHEM 323 and CHEM 324.

EMAC 436. Polymers in Advanced Packaging Systems. 2 Units.
This course serves as a graduate-level introduction to structure-property relationships for many important polymeric materials. Roughly one specific class of polymer will be studied in detail per week, with analysis and discussion that includes discovery history, physical structure (e.g., morphology) and processing, and how these relate to mechanical, thermal, optical, transport and other properties important in packaging. Examples of selected polymers include polyolefins, vinyl polymers, polyesters, ionomers, and bio-based plastics. A growing awareness of sustainability considerations for packaging with be addressed in the course. Prereq: EMAC 270 and EMAC 276 or Requisites Not Met permission.

EMAC 437. Advanced Polymeric Films. 2 Units.
This course is focused on processing structure and property relationships with particular emphasis on a variety of layered film systems. Two classes will be offered per week, emphasizing a large variety of layered film systems for advanced applications. These film systems exhibit unique properties that allow applications in 1) selective barrier films for food and packaging and flexible photocell protection; 2) optical and photonic characteristics for security-enhanced devices and systems; 3) transport phenomena and separation processes for battery separators and particle separation; and, 4) multilayer films for enhancement of mechanical and adhesive properties. Prereq: EMAC 270 and EMAC 276 or Requisites Not Met permission.

EMAC 438. Packaging Design and Innovation. 3 Units.
The course aims to introduce an enterprise-wide understanding of challenges and opportunities for innovation in packaging design. Students will be introduced to the discipline of product design in the area of advanced packaging systems with an emphasis on needs-based innovation, sustainability, and value creation that leverages technical considerations from a deep understanding of polymer science and engineering. This will be accomplished through an intensive team-based design project selected from a list of topics proposed by industry with fast-feedback via value creation forums and culminating with a functional prototype. An industry representative will co-mentor each team. In addition to a weekly drive toward design and execution of a compelling design project, one class each week will emphasize an important theme that connects to the overall design philosophy. Topics include human factors, sustainability, and marketing among others. Prereq: EMAC 436.

EMAC 450. The Business of Polymers. 2 Units.
This course will link polymer technology to business and management issues that need to be considered for successful technology commercialization. Topics include project management, finance, opportunity assessment, the voice of the customer, and protection of intellectual property. Case studies from both large and small companies will be used to illustrate key concepts. Recommended preparation: EMAC 270, EMAC 276.

EMAC 453. Foundations of Scattering. 3 Units.
Introduction to the fundamentals of using scattering techniques to characterize the structure and dynamics of soft matter and its interfaces, with an emphasis on X-ray and neutron techniques. Topics covered include a mechanistic description of scattering processes, diffraction, small-angle scattering, reflectometry, and quasi-elastic scattering applied to polymers, proteins, gels/networks, nanoparticles, and other soft materials. Offered as EMAC 353 and EMAC 453. Prereq: EMAC 402 and EMAC 403.

EMAC 461. Chemistry of Fire Safe Polymers and Composites. 3 Units.
Chemistry of Fire Safe Polymers and Composites starts with the introduction of characterization techniques used for fire safe materials and combustion phenomena research. General discussion on how reduced flammability of polymers and composites are obtained, for example by additives and preparing intrinsically thermally stable chemical structure and some examples of smart approaches, will be discussed. It also discusses the synthetic methods of preparing high temperature stable polymers in addition to the raw materials used to prepare those materials. Special emphasis will be placed on the thermal stability data obtained by thermogravimetric analysis (TGA) and combustion calorimetry for those fire safe materials. Mechanistic aspects of the flammability of polymers will be explained with special emphasis on the molar contribution of chemical functionality to the heat release capacity. Theoretical derivation of thermokinetic parameters will be explained. In addition, a common sense build-up will be attempted by providing actual numbers associated with those thermokinetic parameters. Upon completion of background formation, a more advanced materials, composites and nanocomposites, will be discussed using the results recently reported. Preliminary attempts to explain flame retardation by nanocomposite structures will also be discussed. Offered as EMAC 461 and EMAE 461.
EMAC 463. Fire Dynamics. 3 Units.
This course introduces compartment fires and burning behavior of materials. Topics include: buoyant driven flow, fire plume, ceiling jet, vent flow, flashover and smoke movement as well as steady burning of liquids and solids; ignition, extinction and flame spread over solids. Recommended Preparation: Elementary knowledge in thermo-fluids is required. Offered as EMAE 463 and EMAC 463.

EMAC 464. Fire Protection Engineering. 3 Units.
This course introduces essentials of fire protection in industry and houses. Topics include: hazard identification (release of flammable gases and their dispersion), fire and explosion hazards, prevention and risk mitigation, fire detection systems, mechanisms of fire extinguishment, evaluation of fire extinguishing agents and systems. Offered as EMAC 464 and EMAE 464.

EMAC 471. Polymers in Medicine. 3 Units.
This course covers the important fundamentals and applications of polymers in medicine, and consists of three major components: (i) the blood and soft-tissue reactions to polymer implants; (ii) the structure, characterization and modification of biomedical polymers; and (iii) the application of polymers in a broad range of cardiovascular and extravascular devices. The chemical and physical characteristics of biomedical polymers and the properties required to meet the needs of the intended biological function will be presented. Clinical evaluation, including recent advances and current problems associated with different polymer implants. Recommended preparation: EBME 306 or equivalent. Offered as EBM 406 and EMAC 471.

EMAC 475. Fundamentals of Non-Newtonian Fluid Mechanics and Polymer Rheology. 3 Units.
This course will involve the study of Rheology from the perspectives of rheological property measurement, phenomenological and molecular models, and applicability to polymer processing. In particular, students will be introduced to: 1) General concepts of Rheology and Newtonian Fluid Mechanics, 2) Standard flows and material functions, 3) The role of Rheology as a structural characterization tool, with an emphasis on polymeric systems; 4) Experimental methods in Rheology with quantitative descriptions of associated flows and data analyses; 5) Viscoelasticity and Non-Newtonian Fluid Mechanics, including the application of models, both phenomenological and molecular, to the prediction of rheological behavior and extraction of model parameters from real data sets; and 6) The relevance of rheological behavior of different systems to practical processing schemes, particularly with respect to plastics manufacturing. Offered as EMAC 375 and EMAC 475. Prereq: ENGR 225 or EMAC 404.

EMAC 476. Polymer Engineering. 3 Units.
Mechanical properties of polymer materials as related to polymer structure and composition. Visco-elastic behavior, yielding and fracture behavior including irreversible deformation processes. Recommended preparation: ENGR 200. Offered as EMAC 376 and EMAC 476.

EMAC 477. Elementary Steps in Polymer Processing. 3 Units.
This course is an application of principles of fluid mechanics and heat transfer to problems in polymer processing. In the first part of the course, basic principles of transport phenomena will be reviewed. In the second part, the elementary steps in polymer processing will be described and analyzed with application to a single screw extruder.

EMAC 478. Polymer Engineer Design Product. 3 Units.
Uses material taught in previous and concurrent courses in an integrated fashion to solve polymer product design problems. Practicality, external requirements, economics, thermal/mechanical properties, processing and fabrication issues, decision making with uncertainty, and proposal and report preparation are all stressed. Several small exercises and one comprehensive process design project will be carried out by class members. Offered as EMAC 378 and EMAC 478. Counts as SAGES Senior Capstone.

EMAC 479. Advanced Polymer Engineering. 2 Units.
This Advanced Polymer Engineering course will focus on the ultimate engineering properties for polymers, including fracture mechanics, electrical, and optical properties of polymers. For polymer fracture mechanics, deformation and fracture behavior of polymers will be introduced. The electrical properties include both insulation and conduction/semiconduction properties for polymers. In the optical property section, we will introduce polymer photonics and polymers in liquid crystal displays. The goal of the course is to help students achieve fundamental understanding of advanced polymer properties. EMAC 479 students will do an additional project design. Offered as EMAC 379 and EMAC 479. Prereq: EMAC 404.

EMAC 491. Polymers Plus Literature Review. 1 Unit.
This course involves weekly presentations of the current polymer literature. It involves at least one presentation by the enrolled student and participation in all literature reviews (at least 10/semester). The course will focus on presentation skills (both oral and written), scientific interpretation, and development of peer-review skills. This course can be taken for a total of 3 credits over three different semesters.

EMAC 500T. Graduate Teaching II. 0 Unit.
This course will engage the Ph.D. students in teaching experiences that will include non-contact (such as preparation and grading of homework and tests) and direct contact (leading recitations and monitoring laboratory works, lectures and office hours) activities. The teaching experience will be conducted under the supervision of the faculty. All Ph.D. students will be expected to perform direct contact teaching during the course sequence. The proposed teaching experiences for EMAC Ph.D. students are outlined below in association with graduate classes. The individual assignments will depend on the specialization of the students. The activities include grading, recitation, lab supervision and guest lecturing. Recommended preparation: Ph.D. student in Macromolecular Science.

This course aims to provide a broad overview of the structure and function of cellular macromolecules, with the major focus being an exploration biological cells as soft materials. Special emphasis is given to connections between cell material properties and macromolecular assemblies (e.g., viscoelasticity and cytoskeletal networks) and roles in determining mechanical, physical, electrical and transport properties. Material properties of collections of cells, namely selected tissues and organs, will be also discussed with special attention to irritability and motion and the design of smart materials and artificial cells using fundamental concepts from macromolecular science and engineering.
EMAC 600T. Graduate Teaching III. 0 Unit.
This course will engage the Ph.D. students in teaching experiences that will include non-contact and direct contact activities. The teaching experience will be conducted under the supervision of the faculty. The proposed teaching experiences for EMAC Ph.D. student in this course involve instruction in the operation of major instrumentation and equipment used in the daily research activities. The individual assignments will depend on the specialization of the students. Recommended preparation: Ph.D. student in Macromolecular Science.

EMAC 601. Independent Study. 1 - 18 Units.
(Credit as arranged.)

EMAC 651. Thesis M.S.. 1 - 18 Units.
(Credit as arranged.)

EMAC 673. Selected Topics in Polymer Engineering. 2 - 3 Units.
Timely issues in polymer engineering are presented at the advanced graduate level. Content varies, but may include: mechanisms of irreversible deformation: failure, fatigue and fracture of polymers and their composites; processing structure-property relationships; and hierarchical design of polymeric systems. Recommended preparation: EMAC 376 or EMAC 476.

EMAC 677. Colloquium in Macromolecular Science and Engineering. 0 - 1 Units.
Lectures by invited speakers on subjects of current interest in polymer science and engineering. This course can be taken for 3 credits over three different semesters.

EMAC 690. Special Topics in Macromolecular Science. 1 - 18 Units.

EMAC 695. Project M.S.. 1 - 9 Units.
Research course taken by Plan B M.S. students. Prereq: Enrolled in the EMAC Plan B Program.

EMAC 701. Dissertation Ph.D.. 1 - 9 Units.
(Credit as arranged.) Prereq: Predoctoral research consent or advanced to Ph.D. candidacy milestone.