POLYMER SCIENCE AND ENGINEERING
UNIVERSITY OF MASSACHUSETTS AMHERST

Polymers are everywhere! Nature stores information in DNA, a polymer, and makes incredibly strong and intricate structures such as spider webs and butterfly wings, also polymers. We constantly discover new ways to use polymers to better our world. While common plastics are at the low end of the application spectrum, high technology polymers are at the other: from contact lenses and airplane composites to bullet-proof vests, fire-resistant materials, flash memory, and a myriad of other modern products. For more than 50 years, PSE has defined the frontier and guided the world-wide understanding of polymers. Advancing the science and engineering of polymers while training students to do the same is our core mission.

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UMASS AMHERST

OVERVIEW OF PSE

Polymer Science and Engineering (PSE) at UMass began as a doctoral program in 1966 and became an academic department in 1974. Since then, PSE has gained an international reputation while educating over 800 Ph.D. scientists and engineers. Reflecting a wealth of opportunities for those trained in the discipline, PSE graduates hold high-level positions in industry and academia across many fields of science and engineering. Of those graduated since 2010, more than 98% are employed in polymer-related positions.

PSE is pursuing societally relevant intellectual themes in areas such as nanotechnology, upcycling of plastics, biotechnology, energy generation and storage, and water purification. Faculty members have won numerous national and international awards (essentially all that are available in the field) and are members of the National Academies of Engineering and Science; likewise, PSE students and alumni win prestigious professional awards each year. Research funding per faculty member is among the highest across all academic departments/disciplines in the nation. The Department's research perspectives are flexible and collaborative, facilitating the pursuit of exciting new research directions as topics and technologies evolve. The physical home of PSE, the Conte National Center for Polymer Research, offers a state-of-the-art lab environment, and within its confines, there are unrivaled facilities for polymer synthesis, characterization, and processing.

PSE has the three-fold objectives common to all research-oriented academic departments: research, teaching, and service. PSE's teaching mission focuses on the training of doctoral students in the fundamental principles of polymeric materials. The objective is to endow a broad-based expertise. Thus, each student is expected to master the fundamentals of polymers as derived from fields such as chemistry, physics, engineering, biology and medicine, and materials science and engineering. This breadth distinguishes PSE training from that offered in traditional academic departments, where students might learn polymer chemistry but not polymer engineering, or polymer physics but not polymer chemistry. A PSE alumnus can synthesize polymer materials, measure their properties, and understand the relationships between properties and molecular structure. PSE training also provides the soft skills needed to formulate and implement research strategies for solving the diverse fundamental problems arising in the context of polymer materials.

PSE's research mission is to elucidate the fundamental principles of polymeric materials and put these principles into practice through the preparation of new materials with useful properties. This mission places PSE's research at the forefront of advances in chemistry, engineering, biology, physics, and materials science and engineering. To further impacts, frequent excursions beyond the traditional bounds of polymer science and engineering are encouraged, and research targets often are "soft materials", containing additional elements such as nanoparticles, ionic liquids, cellulose nanocrystals, and graphene sheets. Over time, the polymer subfields that offer the most exciting challenges change, and PSE has an excellent track record in anticipating these changes and repositioning its research to make the most of opportunities. At the current time much PSE research focuses toward nano-manufacturing, sustainability, medicine and biomedical materials, interface science, alternative energy technologies, and green chemistry.

Polymers frame a young and dynamic field, and PSE thereby has a responsibility as a leading department to guide new teaching and research practices for the entire field, not just for its own students. There are various avenues for fulfilling these service responsibilities, but engagement in professional societies, editing of journals, writing of texts and monographs, and initiating of scientific collaborations are among the most important. PSE plays major roles in all.

PSE embraces further responsibilities for increasing equity and diversity within its community and to maintain a positive workplace that supports all members.

Faculty Members

The PSE faculty supports a spectrum of polymer research and teaching interests. Just 4 of the 17 faculty members have academic polymer degrees, the others coming to polymers with training in an affiliated academic discipline. Further, several of the faculty members gained extensive industrial polymer experience prior to a return to academia. Such multifaceted but overlapping experiences facilitate interdisciplinary and multidisciplinary approaches to the Department's central missions. The faculty is intensely devoted to collaboration, with the majority of research projects co-directed by two or more faculty members, and the majority of courses co-taught. It is not unusual for a student to be co-advised by a chemist and an engineer, although faculty members are difficult to categorize in this way, as individual perspectives typically blend aspects across science and engineering.

PSE faculty members have won all the major awards of the polymer field. By many measures, the PSE Ph.D. program ranks at the very top of the polymer world. In recent rankings, such as the one conducted by the National Research Council (NRC), PSE was placed well above competing U.S. academic polymer programs, continuing a tradition that goes back several decades. In such rankings, PSE is often compared to departments of materials science and engineering, although the Department's fit to this grouping is inexact. In the most recent NRC rankings of all graduate programs in the nation, PSE's position in the materials discipline was between #3 and #8 (depending on how the rankings are interpreted), a remarkable performance given PSE's particular scope. Interestingly, in the last *U.S. News and World Report* ranking of PSE, the department was given the #1 spot in the polymer chemistry sub-category.

Students

Incoming class sizes for PSE have recently ranged from 17 to 26. Augmenting them are doctoral students from the UMass Departments of Chemistry, Physics, and Chemical Engineering who elect to conduct thesis projects under PSE advisors. Students do research alongside approximately an additional 30 postdoctoral fellows and visitors. Beyond these groups, a number of exchange students from Mainz and other international universities and institutes take courses alongside the first-year PSE class.

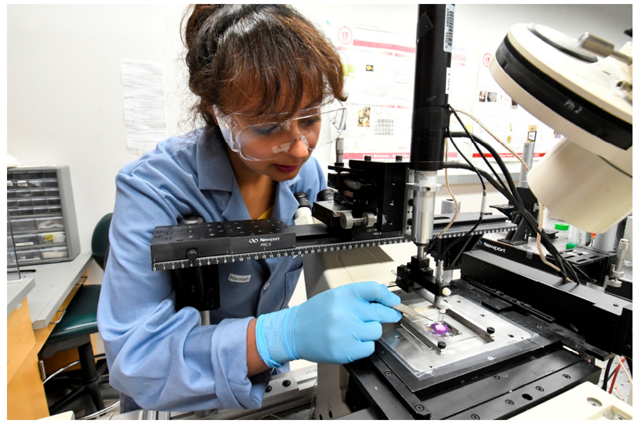
PSE students are actively involved in many polymer outreach programs, which seek to educate the broader public about polymers, and several such programs are now primarily student-run. For example, students initiated the highly popular ASPIRE, a month-long lab program for outstanding area high school students. Senior PSE students also run a mentoring program for the incoming students, providing support as they master unfamiliar academic topics and choose their advisors. The PSE Club organizes regularly social events, sport teams, and other leisure activities for students.

Most PSE students receive departmental stipend support in their first year, although outstanding individuals may find support in the form of distinguished fellowships such as those awarded by the National Science Foundation, NASA, or the Gates Foundation. Funding after the first year of study, which is focused on coursework, is provided by a student's advisor(s). All stipend support is contingent on satisfactory progress towards degree, and department policy mandates that stipends be awarded to all students who meet this standard. PSE does not offer stipends in the form of teaching assistantships; students involved in teaching (only allowed after the first year) are given stipend supplements.

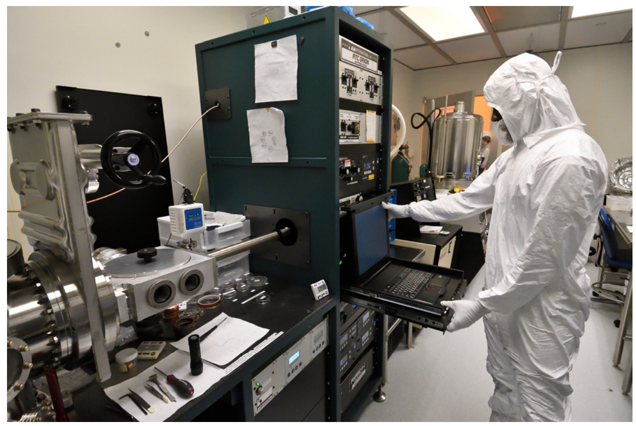
The job search for students approaching graduation is pursued in a variety of ways, with the department hosting interviews each fall by many large U.S. and international companies. Job opportunities are abundant; in recent years, most graduating students have had to choose among multiple job offers. A recent 10-year survey of PSE alums (168 alums in total) found that almost 100% were employed, with approximately 98% working in a job related to their polymer education. The median time to degree is close to 5 years, well below the U.S. average for Ph.D. scientists and engineers.

FACILITIES

The world-class polymer research facilities at the University of Massachusetts are run by a highly experienced technical staff. Most facilities are located in the 172,000 sq. ft. Silvio O. Conte National Center for Polymer Research, the home of the Polymer Science & Engineering Department. While much of the Conte Center's space is devoted to individual faculty-directed projects and equipment, as the attached list attests, the base of shared instruments and facilities is substantial. These facilities span the range of polymer instrumentation needs, from those principally supporting activities of polymer synthetic chemists to those principally supporting activities of polymer engineers and physicists. Some of the instruments are unique and many of the instruments are expensive, some costing in excess of $1 million.



Support for shared instruments comes from a variety of sources but access to these instruments is straight forward. Typically, students are first educated on an instrument under the supervision of the technical staff, but afterwards, are expected to run even the most complex instrument themselves, perhaps seeking occasional advice from the facility staff. Over the course of their Ph.D. studies, students may actually spend more time in the various instrument facilities than in their own advisor's labs. To facilitate student use, when usage charges are needed, hourly fees are kept low.



The total value of available research instrumentation exceeds $35 million. In the rare instance when local equipment is insufficient, a student may travel to another university, a national laboratory, and even to an overseas university to conduct experiments. PSE students routinely do neutron and synchrotron x-ray scattering experiments at Brookhaven or Argonne National Laboratories and elsewhere.

CENTRAL FACILITIES AND SHARED EQUIPMENT

Keck Electron Microscopy Facility, housing JEOL JEM2200 FS (energy-filtered TEM), JEOL-2000FX (200 keV high resolution TEM), FEI Tecani 12 (120 KeV TEM), FEI-Magellan 400 (extreme high-resolution field emission SEM with energy dispersive x-ray spectroscopy); a variable pressure SEM with integrated microtome will arrive shortly. The facility has attachments/accessories for cryo-TEM, vacuum evaporators, a table-top SEM, and an assortment of microtomes.

Keck Nanostructures Laboratory, hosting 3 AFM instruments suitable for the imaging of solid surfaces in contact with either air or liquids, variable angle spectroscopic ellipsometer, nanoindenter, optical interferometer, and stylus profilometer.

X-Ray Scattering Facility, hosting separate instruments for diffractometry, small-angle x-ray scattering (SAXS), and wide-angle x-ray scattering (WAXS).

Thermal Analysis Facility, including two DSCs, DMTA, TGA, and DETA.

Mass Spectrometry Facility, hosting high-resolution sector, ion trap, and MALDI TOF instruments.

Liquid Chromatography Facility, including high temperature GPC (light scattering detection), five room-temperature GPCs (some with single and some with multiple angle light scattering detection).

Light Scattering Facility, hosting two goniometer-based, multi-angle dynamic light scattering instruments as well as single angle dynamic light scattering instrument capable of simultaneous electrophoresis measurement.

Optical Microscopy Facility, with a laser-scanning fluorescence confocal microscope along with various fluorescence and white light microscopes.

Rheology and Mechanical Testing Laboratories, possessing a range of rheometers, environmental chambers, and instruments for the steady and dynamic testing of solids.

Surface Analysis Facility, with Bruker XPS, single-angle ellipsometer, and mechanical and optical profilometers.

NMR Facility NMR Facility, housing five high-field instruments with a broad array of capabilities: Agilent 700MHz with Cold Probe®, specialized for biomacromolecule structure elucidation; Bruker 600MHz with Cryoprobe® and autosampler, suitable for both in-depth biomacromolecule structure study and high-throughput screening; Bruker 600MHz with 1.9mm, 4mm, E-free, and Pisema solid-state probes, suitable for a wide range of solid-state NMR experiments, and a diffusion probe, specialized for studies of very slow diffusion of large molecules, micelles and aggregates; Bruker 500MHz with Prodigy® cryoprobe and autosampler for open-access chemical structure determination; Bruker 400MHz with Prodigy® cryoprobe and autosampler for open-access chemical structure determination.

Electronic Materials Facility, centrally locating device fabrication line, UV/Ozone cleaner, spin-coater, surface profilometer, precision oven and hot plate, and vacuum evaporator alongside a two-compartment glove box system containing a solar simulator and measurement kit for assessing quantum efficiency/incident-to-charge carrier efficiency over a broad spectral range.

Conte Nanotechnology Cleanroom (1400 sq. ft. class 1000), containing stations for metallization, e-beam lithography, deposition etch, photolithography, and wet chemistry (laminar flow hood, wafer cleaning/etching);

Roll-2-Roll Fabrication and Processing Facility provides 'soft wall' cleanrooms dedicated to nanomanufacturing, including nanoimprint lithography, nanoindentation, plasma etching, step-and-flash imprint lithography and thermal nanoimprinting. A separate dedicated lab houses web-based tools for the translation of advanced materials and nanomanufacturing processes to industrially relevant scalable platforms for the development of next generation life science innovations in biosensors, diagnostics, and platforms for personalized health monitoring.

Eighteen major shared spectroscopy instruments for optical, infrared, and Raman measurements are scattered throughout the Conte building along with individual shared instruments for purposes such as osmometry, sample preparation (extruders, presses, spinners, fermentors, etc.), chromatography, multiple 3D-printing systems for polymers and metals, etc. Specialized labs include a cold room for molecular biology experiments, two cell culture facilities, and a facility for high speed imaging. Beyond instrument capabilities in Conte, the UMass Institute for Applied Life Sciences houses an array of supervised core facilities accessible to PSE researchers (see https://www.umass.edu/ials/core-facilities)

DEGREE PROGRAM

Incoming PSE students arrive with different academic backgrounds, mostly in disciplines such as chemistry, chemical engineering, and materials science and engineering. Few have extensive formal polymer experience or training.

PSE formally accepts only doctoral students, although masters students can be admitted on an exceptional basis. The department's doctoral students are expected to take the core curriculum in their first year. Nearly all PSE degree candidates take these courses along with a considerable number of outside chemistry, physics, and engineering graduate students. The core courses are split into three areas - polymer synthesis, polymer physics/physical chemistry, and polymer engineering. Synthesis covers all topics associated with the preparation and modification of polymer molecules; physics considers how the structure of polymer molecules affects their dynamics, microstructure, and thermodynamic properties; and engineering deals with the continuum description of polymer materials mechanics and rheology. All PSE students are expected to be conversant in all three areas. Further, through two intensive laboratory core courses, students are expected to gain skills in synthesizing and characterizing a broad range of polymers.

After the first semester of core courses, doctoral students begin to take periodic cumulative examinations, which continue until three are passed; only six examinations can be taken in total. The choice of cumulative examinations as the principal tool for doctoral degree qualifying is based on the premise that students must take some responsibility for their own education. Using their first semester of courses as a basis for self-study, students begin to learn the polymer field based on the foundation of their own academic experience. With curricula and texts less defined than for many other fields, basic mastery of polymers is a multi-faceted task that goes well beyond the classroom.

After completion of the core curriculum and cumulative examinations, doctoral students must present a prospectus of their thesis research (oral and written), an independent research proposal (oral and written), and an oral data defense at the end of thesis research. The data defense prepares the students and their thesis committee for the last two steps in the degree- the writing of the Dissertation and its oral defense. In the second and subsequent years of study, most doctoral students take special topics courses, although none are formally required. In addition, various professional development activities are incorporated into the curriculum as workshops or short courses. These are expected to address issues germane to the career of a doctoral scientist but which remain outside the intellectual fundamentals of the discipline.

Students are given a choice of research topics/groups in their first semester, and after selecting an advisor, they are expected to attend appropriate groups meetings until graduation. PSE group meetings vary in character but at a minimum, involve weekly presentations by group members, which serve to keep the group abreast of ongoing research and to develop oral presentations skills. Many advisors expect their students to attend regular meetings of larger scale, possibly involving students/postdoctoral fellows/faculty members from multiple groups/departments.

PSE has several undergraduate offerings to the larger university community, an upper-level polymer overview classes and multiple freshman seminars. They are typically taken by undergraduates and graduates from departments in the sciences and engineering.

CURRICULUM

PSE students in their first year are engaged in courses that cover the basic concepts and modern methods of synthetic polymer chemistry, polymer physics, and polymer engineering. This broad spectrum of courses conveys material central to polymer science and engineering, and includes topics on which all Ph.D. students in the program should be conversant. In addition, the majority of questions found on the cumulative exams are based on the content of these courses.

FALL

602 Polymer Characterization Laboratory
603 Polymer Synthesis Laboratory
604 Introduction to Polymer Engineering
607 Introduction to Synthetic Polymer Chemistry
608 Physical Chemistry of Polymers I

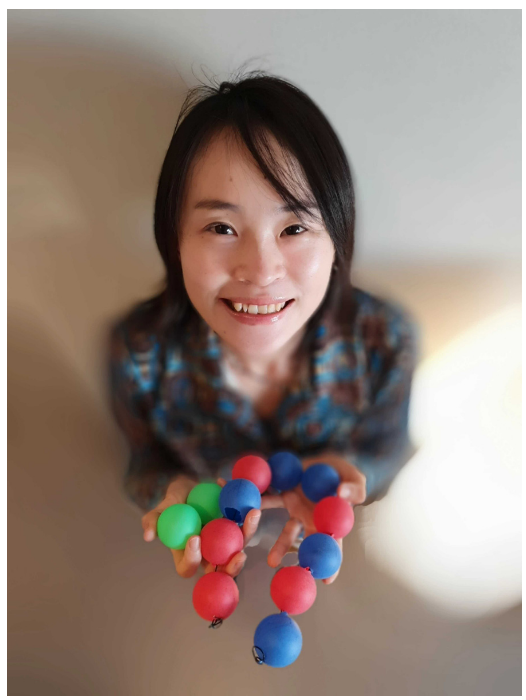
SPRING

797X Advanced Polymer Engineering
760 Organic Polymerization Reactions
789 Physical Chemistry of Polymers II
721 Morphology of Polymers

SPECIAL TOPICS COURSES

A wide variety of advanced topic courses are also offered. These courses are generally smaller in enrollment compared to the first year curriculum and taken in the second year and beyond. Most PSE students enroll in one or more advanced topics courses per year, to provide in-depth coverage of more focused academic subjects. Many advanced topic courses are taught by visiting faculty who bring unique expertise or perspectives to PSE. A list of special topics courses which have been presented recently is given below:

Polymer Therapeutics
Polymers in Nanoscience and Nanotechnology
Polymer Adhesion
Silicon-Containing Polymers
Conducting Polymers
Viscoelasticity
Polymer Properties
Micromechanics
Interaction of Radiation with Matter
Polymer Surfaces
Polymer Reaction Engineering
Vibrational Spectroscopy of Macromolecules
Biopolymers
Colloidal Phenomena
Polymer Rheology
Polymer Processing
Mechanics of Polymers and Composites
Excellence in Polymer Education
Advanced NMR Spectroscopy
Advanced Polymer Technologies
Polymer Theory
Special Topics in Engineering Mechanics



SPECIAL COURSE OFFERINGS BY PSE FACULTY MEMBERS TO INDIVIDUAL RESEARCH GROUPS

The final course category is group meetings, offered by most faculty and taken primarily by students studying with that professor. A list of group meeting courses is given below:

897LB	BRADLEY - Interfacial Synthesis and Assembly
897O	BERMUDEZ - Engineering Approaches to Biological Problems
797BB	CARTER - Nanopatterned Polymers and Surface Chemistry
897B	COUGHLIN - Polymer Chemistry
897F	CROSBY - Surface& Interfacial Mechanics
897E	EMRICK - Synthetic Polymers and Nanostructures
897G	GIDO - Polymer Microscopy
897GG	GRASON - Geometry of Polymeric Assemblies
797E	HOAGLAND - Polymer Solutions
897RK	KATSUMATA - Design of functional Interfaces
897L	LESSER - Polymer Fracture
803	MCCARTHY - Synthetic Polymer Chemistry
897A	MUTHUKUMAR - Polymer Dynamics
897R	RUSSELL - Polymer Surfaces & Interfaces
897M	SANTORE - Colloidal and Macromolecular Interfaces
897T	TEW - Well Defined Macromolecular Architectures
897W	WATKINS - Nanoscale Materials

DEPARTMENTAL SEMINAR

A few PSE courses do not conveniently fall into any of the categories. Of these, the departmental seminar is the most important. The Department expects all registered students, including those in their first year, to enroll each semester and attend the weekly departmental seminar series.

COURSE DESCRIPTIONS

INTRODUCTORY COURSES

For first year undergraduate students

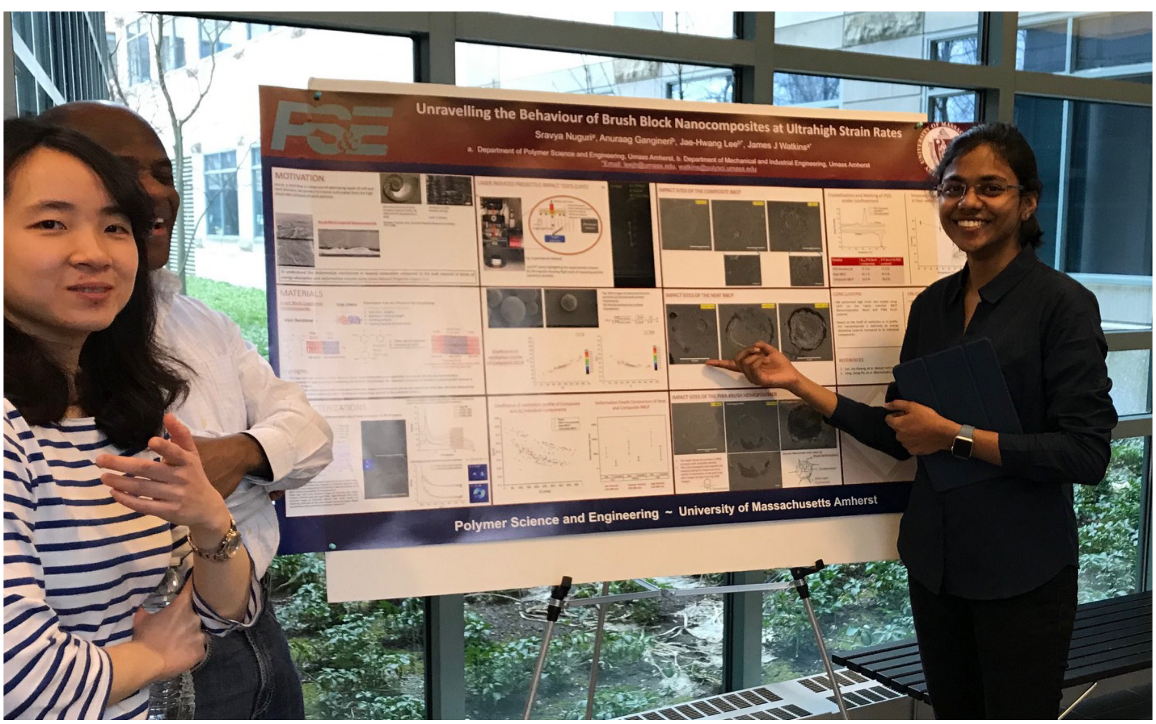
197 POLY: The Freshmen seminar course, "The Age of Polymers"

The rise of human civilization is marked by the development of ever more advanced materials: Stone Age, Bronze Age, Iron Age. How will future historians refer to our time? The Silicon Age, or Perhaps the Age of Polymers? Polymers encompass a broad spectrum of our world from the mundane, such as plastics for packaging, to the cutting edge, such as the wings of advanced aircraft, or flexible electronic devices. The DNA that encodes the blueprints for life, and the proteins that build our bodies, are also polymers. Professors in the Polymer Science and Engineering Department will introduce first year students to polymer enabled advances and opportunities in biomedical engineering, electronics, energy, packaging, clothing and other important applications.

For junior or senior undergraduate students, graduate students from Chemistry, Chemical Engineering, Physics and other departments

PSE 501: Introduction to Polymer Science & Engineering

PSE 501 is for students with a basic training in chemistry, physics, or engineering. This course offers a survey of preparative methods of polymers; physical chemistry of polymer molecules in solution, liquid, and solid phases; thermodynamics and statistics of polymers; methods of characterization; mechanical properties and fabrication techniques. In recent years, enrollment in this popular course has been high (>100) and distributed from a broad base of undergraduate majors: chemical engineering (~50%); chemistry (~20%); mechanical engineering (~10%); physics (~10%); and food science (~10%).



CORE COURSES

Synthesis

PSE 607: *Introduction to Polymer Synthesis, Fall Semester*

In PSE 607, students are taught the principles of synthetic polymer materials, starting with polymer structure, classification, and nomenclature, then proceeding to traditional topics in step-growth (polycondensation) and chain-growth polymerization. The course is typically shared between two faculty members, one covering step-growth and the other covering chain-growth polymerization. Step growth topics include the major classes of polymer materials (e.g., polyester, polyamide, epoxy polymers, polysiloxane, etc.), while the chain-growth portion covers many types of vinyl polymers (e.g., polystyrene, poly(methylmethacrylate), etc.) and ring-opening polymerization (e.g., to give polylactide, polyethylene oxide, etc.), while touching lightly on transition metal-mediated olefin polymerization (this is covered in greater detail in PSE 760). In addition to synthesis, basic polymerization kinetics of step-growth, chain-growth, and living polymerization are described. To address some deficiency in organic chemistry, some faculty weave organic chemistry concepts into the course, while others use the first several lectures of the semester as an organic chemistry review.

PSE 603: Synthetic Polymer Laboratory, Fall Semester

PSE 603 is a laboratory course in which students prepare and execute experiments in synthetic polymer chemistry. There is a one hour lecture, and one 4-5 hour lab session each week. Two faculty members share instruction, and four PSE students serve as TAs. The first two weeks are devoted to techniques (distillation and crystallization), and the remaining ten weeks involve syntheses, including, for example, polyethylene terephthalate by condensation polymerization, poly(caprolactam) by ring-opening polymerization, polystyrene by anionic polymerization, and poly(methyl methacrylate) by atom transfer radical polymerization. In recent years, the course has been modernized and TAs have been inserted into the lecture component (each TA gives two lectures). It should be noted that part of the value of PSE 603 involves the pairing of synthetic with non-synthetic PSE students to carry out the experiments.

PSE 760: Advanced Organic Polymer Chemistry, Spring Semester

In principle, PSE 760 covers topics that build on the basics of PSE 607. Since 2001 the course has been split among three faculty members, each covering about 5 weeks (10 lectures). This synthetic PSE course, covers olefin polymerization chemistry, from transition metal catalysis to polyolefin properties arising from different syntheses (Ziegler-Natta, metallocene, chain-walking, etc.). Other 5 week topics have included ring-opening polymerization, protein and other biomolecule chemistry, polymers in lithography, and polymers in nanoscience and nanotechnology.

Physics / Physical Chemistry

The physical chemistry core curriculum provides a solid grounding in the statistical properties, thermodynamics, phase behavior, and morphology of polymers. Comparable subjects would traditionally be covered in far less detail in a one-semester undergraduate or graduate course on polymer physics at other universities. Throughout the physical core course sequence, connections are drawn to the synthetic chemistry and engineering curricula by highlighting the ways in which the chemical structure of polymers influences basic physical properties and how molecular-scale phenomena give rise to macroscopic behavior of polymers.

PSE 608: Physical Chemistry of Polymers I, Fall Semester

In PSE 608, students learn about the statistics and conformations of individual polymer chains, providing a foundation for understanding the properties of multi-chain systems, including concentrated solutions and polymer melts. A review of classical thermodynamics is included to allow students from diverse backgrounds to apply the principles of phase equilibria to polymeric systems. Finally, the theoretical underpinnings of scattering experiments are introduced, and the importance of these techniques for characterizing polymers in solution and in the solid state is discussed.

PSE 602: Polymer Characterization Laboratory, Fall Semester

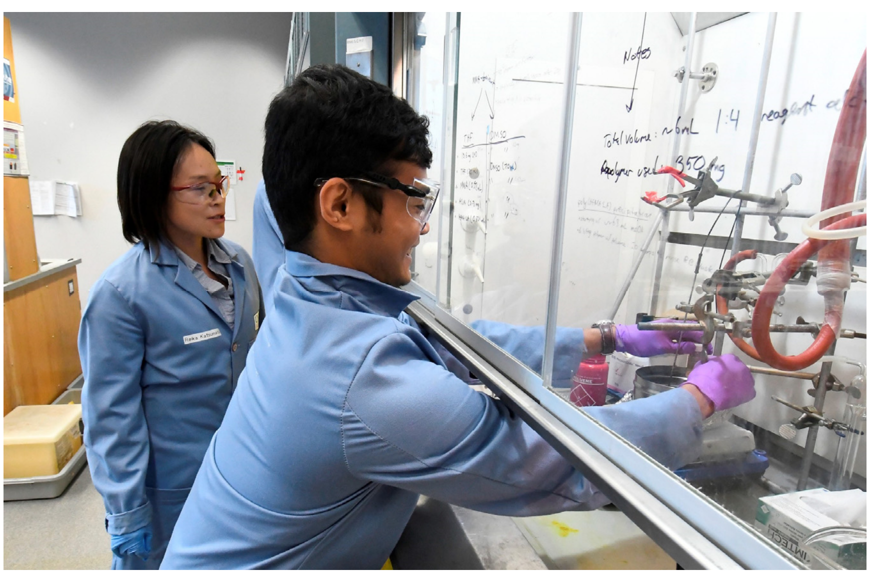
Hands on characterization of polymers by up to fifteen methods, including spectroscopic (nuclear magnetic resonance, Raman, infrared), mechanical (tensile, dynamic mechanical, rheological), microscopic (electron and optical microscopy), physiochemical (intrinsic viscosity, differential scanning, calorimetry, gel permeation chromatography) and scattering (light, x-rays). Molecular simulation techniques introduced. Lectures provide a state-of-the-art description of these and additional polymer characterization methods. Additional emphasis is placed on student communication skills. Students prepare comprehensive laboratory reports and make oral presentations on both the underlying theory and results of their analyses.

PSE 789: Physical Chemistry of Polymers II, Spring Semester

In PSE 789, students are introduced to the dynamics and mechanical properties of polymeric systems. This includes solution dynamics, melts, entanglements and reptation theory, glassy behavior, crystallization, and rubber elasticity.

PSE 721: Morphology of Polymers, Spring Semester

PSE 721 covers the fundamental experimental techniques used to characterize polymeric structure, and in particular, scattering and electron microscopy. Topics include semi-crystalline polymers, polymer blends, block copolymers, and liquid-crystalline polymers.



Engineering

In contrast to core courses in synthesis and physical aspects of polymers, the engineering courses are characterized by a continuum rather than a molecular focus; molecular level dynamics and structure are often discussed in class in anticipation of their continuum effects, but analysis always proceeds at the continuum level.

PSE 604: Introduction to Polymer Engineering, Fall Semester

PSE 604 is an introductory course that can be handled by all PSE students, including those with no engineering background (about half the entering class). Students are expected to be able to solve ordinary differential equations and be familiar with methods for solving partial differential equations. After introducing overarching concepts such as stress, strain, and tensor analysis, the course turns to solids mechanics, fluid mechanics, and diffusion. Although spun in terms of polymers, the basic concepts are treated at similar depth as traditional undergraduate engineering courses. Typically, two PSE faculty members share PSE 604.

PSE 797X: Advanced Polymer Engineering, Spring Semester

PSE 797X covers linear viscoelasticity, nonlinear deformation of solids (yielding, fracture), and rheology (flow of non-Newtonian fluids), and in some years, adhesion. Depending on the number of topics incorporated, three or four instructors may be assigned to 797X.