

# Institute for Molecular Engineering

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ime.uchicago.edu

Dean and Pritzker Director

- Matthew Tirrell

**Academic and Student Affairs**

- Juan de Pablo, Director of Graduate Studies
- Rovana Popoff, Associate Dean and Dean of Students
- Novia Pagone, Associate Dean of Students

**Faculty**

- David Awschalom ([http://ime.uchicago.edu/awschalomlab/people/david\\_awschalom](http://ime.uchicago.edu/awschalomlab/people/david_awschalom))
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- Juan de Pablo ([http://ime.uchicago.edu/de\\_pablo\\_lab/people/juan\\_de\\_pablo](http://ime.uchicago.edu/de_pablo_lab/people/juan_de_pablo))
- Giulia Galli ([http://ime.uchicago.edu/giulia\\_galli](http://ime.uchicago.edu/giulia_galli))
- Supratik Guha ([http://ime.uchicago.edu/ghu\\_lab/people/supratik\\_guha](http://ime.uchicago.edu/ghu_lab/people/supratik_guha))
- Alex High (July 2017, Quantum Information Technologies)
- Jun Huang ([http://ime.uchicago.edu/huang\\_group/people/jun\\_huang](http://ime.uchicago.edu/huang_group/people/jun_huang))
- Jeffrey Hubbell ([http://ime.uchicago.edu/hubbell\\_lab/people/jeffrey\\_hubbell](http://ime.uchicago.edu/hubbell_lab/people/jeffrey_hubbell))
- Nancy Kawalek ([http://ime.uchicago.edu/nancy\\_kawalek](http://ime.uchicago.edu/nancy_kawalek))
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The Institute for Molecular Engineering (IME) is at the forefront of an emerging field. This exciting venture prepares students to combine problem-solving skills with broad expertise in the fundamental sciences to build useful systems from the molecular level up. The IME's approach to engineering research and education emphasizes analytical and disciplinary integration, rather than the traditional separation of engineering disciplines. As a result, students from diverse scientific backgrounds may collaborate on research projects that involve the incorporation of synthetic molecular building blocks, including electronic, optical, mechanical, chemical, and biological components, into functional systems that will impact technologies from advanced medical therapies to quantum computing.

Established in 2011 by the University of Chicago, in partnership with Argonne National Laboratory (<http://www.anl.gov>), the IME brings together a growing team of world-class researchers from diverse science and engineering disciplines who take a hands-on approach to mentoring students and cultivating relationships with industrial and academic partners - resulting in exciting discoveries, new technologies, and innovative solutions.

IME researchers conduct their work at the William Eckhardt Research Center, one of the largest and most modern accessible nanofabrication facilities in the Midwest, which includes cutting-edge clean rooms, molecular imaging facilities, biomolecular research labs, and a wet-lab for nanofabrication and other materials work. Additionally, Argonne National Laboratory brings important resources to the endeavor, including the Advanced Photon Source (<http://www.aps.anl.gov>), the Argonne Leadership Computing Facility (<http://www.alcf.anl.gov>) and the Center for Nanoscale Materials (<http://nano.anl.gov>).

## How to Apply

The Institute for Molecular Engineering welcomes students with diverse academic backgrounds, including all fields of physical, biological and computational sciences, who possess the motivation and background to transcend disciplinary boundaries and pursue research in a bold, problem-focused way. Applicants to the Ph.D. program should have a bachelor's degree in a STEM field and should provide scores for the GRE general test and the TOEFL (if not a native English speaker). The relevant GRE subject test scores will be considered if submitted, and could strengthen an application, but are not strictly required. Please submit a personal statement of research interests, three recommendation letters, and transcript(s) from all undergraduate and graduate institutions, along with payment of the \$90 application fee. Applications are due January 5, 2017. <https://apply-ime.uchicago.edu/apply>

## Degree Requirements

Graduate students entering the IME Ph.D. program are expected to fulfill a set of course requirements including 3 core courses, 4 in-depth courses in the area relevant to their research field of choice, and 2 broad elective courses. The core and in-depth courses are selected from a portfolio of graduate-level courses, in conjunction with the faculty advisor. These courses are offered by the IME, sister departments (Physics, Chemistry, Biophysics, Computer Science and Biological Sciences) or developed specifically for IME students. The broad electives are to provide students with the opportunity to acquire skills in leadership, communication, technology development and product design. The hallmark of IME's Ph.D. program is a highly customized curriculum tailored to each individual student's needs and inspirations.

The vibrant and diverse research activities pursued by IME faculty members offer students a broad range of research opportunities. First-year students explore these opportunities through a required first-year colloquium, a series of faculty research talks during autumn quarter, and by establishing relationships with individual faculty members. As the Institute works in a highly interdisciplinary environment, there are many opportunities to work with multiple faculty members within the Institute and/or with faculty in other partner institutes at the University of Chicago and Argonne National Laboratory (see our website (<http://ime.uchicago.edu/partners>) for a full list). Every effort will be made to facilitate the matching of each student with one of their preferred advisors by the end of the first term.

Some students may be recommended for a terminal M.S. degree. Such students must have registered full time in the division for a minimum of three quarters, have completed nine 30000-level courses in STEM departments with grades of C or better, and have completed at least 200 units of research with an approved faculty member. In addition, these students may, at the discretion of the Director of Graduate Studies, be required to submit a paper on their research.

To establish candidacy, students are required to develop a research proposal describing the objectives, approaches and expected outcomes of their Ph.D. thesis work. Students will give an oral presentation of their written proposal in front of a faculty review committee for approval. This process should be completed no later than the end of the Winter quarter of the second year.

All graduate students are expected to have two quarters of teaching experience, or equivalent activity, in order to graduate.

All students will receive scholarship support from the Institute for the first quarter. Subsequently, IME provides full financial support to all graduate students throughout their graduate study at the IME as long as they remain in good standing.

The IME adopts the residency requirement of the University of Chicago as a part of the degree requirements

## Molecular Engineering Courses

### **MENG 30000. Introduction to Emerging Technologies. 100 Units.**

This course will examine five emerging technologies (stem cells in regenerative medicine, quantum computing, water purification, new batteries, etc.) over two weeks each. The first of the two weeks will present the basic science underlying the emerging technology; the second of the two weeks will discuss the hurdles that must be addressed successfully to convert a good scientific concept into a commercial product that addresses needs in the market place.

Instructor(s): Matthew Tirrell Terms Offered: Autumn

### **MENG 31000. Material Sciences and Engineering. 100 Units.**

This course will discuss the structure and properties of organic and inorganic materials, ranging from polymeric systems, to metallic alloys; the focus will be on the interrelations between chemical bonding, molecular structure, and the resulting behaviour of materials. The course will address physical, chemical, and processing considerations in materials selections for specific applications.

Instructor(s): Paul Nealey Terms Offered: Autumn

### **MENG 31100. Molecular Science and Engineering of Water. 100 Units.**

This course will cover the properties of the water molecule, hydrogen bonding, clusters, supercritical water, condensed phases, solutions, confined and interfacial water, clathrates, and nucleation. In addition, methods of water purification, water splitting and fuel cells, water in atmospheric and climate science, and water in biology, health and medicine will be discussed.

Instructor(s): James Skinner Terms Offered: Autumn

### **MENG 32000. Mathematical Foundations of Molecular Engineering. 100 Units.**

This course will provide an overview of the general mathematical framework required to describe mass, momentum, energy and electronic transport in gases, liquids and solids. That framework will be illustrated in the context of common problems in diffusion, heat conduction, viscous flow and charge transfer. The course will also provide an introduction to elementary numerical and statistical methods for solution of such problems in representative engineering applications.

Instructor(s): Andrew Spakowitz Terms Offered: Autumn

Prerequisite(s): Required Math Courses in the Core, Algebra, Calculus, Physics

**MENG 32500. Polymer Physics and Engineering. 100 Units.**

This course is an advanced introduction to polymer physics and engineering taught at a level suitable for graduate students in STEM fields. Topics that will be covered include the statistics and conformations of linear chain molecules, thermodynamics and dynamics of polymers, polymer blends and polymer solutions, phase equilibria, networks, gels, and rubber elasticity, linear viscoelasticity, thermal and mechanical properties. A laboratory component will supplement the lectures.

Instructor(s): Paul Nealey Terms Offered: Spring

Prerequisite(s): Background in thermodynamics and transport.

**MENG 32510. Polymer Science and Engineering. 100 Units.**

This course is an advanced introduction to polymer physics and engineering taught at a level suitable for senior undergraduates and graduate students in STEM fields. Topics that will be covered include the statistics and conformations of linear chain molecules, thermodynamics and dynamics of polymers, polymer blends and polymer solutions, phase equilibria, networks, gels, and rubber elasticity, linear viscoelasticity, thermal and mechanical properties. A laboratory component will supplement the lectures.

Terms Offered: Autumn

**MENG 32520. Polymer Synthesis. 100 Units.**

This course introduces the most important polymerization reactions, focusing on their reaction mechanisms and kinetic aspects. Topics include free radical and ionic chain polymerization, step-growth polymerization, ring-opening, insertion, controlled addition polymerization, crosslinking and chemical modification of preformed polymers.

Instructor(s): Stuart Rowan Terms Offered: Spring

**MENG 33000. Thermodynamics and Statistical Mechanics. 100 Units.**

This course will present an overview of thermodynamics and statistical mechanics in the context of molecular engineering applications. Such applications will include prediction of the thermophysical properties of multicomponent gases, solids and liquids, prediction of adsorption processes on surfaces or interfaces, and molecular-level descriptions of synthetic and biological macromolecules in solution. Throughout the course, emphasis will be placed on connecting molecular structure and interactions to measurable macroscopic properties.

Instructor(s): Juan de Pablo Terms Offered: Autumn

Prerequisite(s): Chemistry 26100-26200 or equivalent or the consent of the instructor

**MENG 33310. Experimental Techniques and Advanced Instrumentation. 100 Units.**

This course aims to provide students with a knowledge of state-of-the-art experimental measurement techniques and laboratory instrumentation for applications in broad scientific research environments, as well as industrial and general engineering practice. Topics include atomic-scale structural and imaging methods, electronic transport in low dimensional matter, magnetic and optical characterization of materials. Basic concepts in electronic measurement such as lock-in amplifiers, spectrum and network analysis, noise reduction techniques, cryogenics, thermometry, and vacuum technology, as well as statistical analysis and fitting of data will also be discussed.

Instructor(s): David Awschalom Terms Offered: Spring

Prerequisite(s): Completion of PHYS 23400 & PHYS 23500 for undergraduates.

Equivalent Course(s): MENG 23310

**MENG 33330. Physics of Solid-State Nano-electronic Devices. 100 Units.**

This course covers the fundamental concepts needed to understand nanoelectronic solid-state devices. After an overview of the basic properties of semiconductors and electronic transport in semiconductors, the p-n junction, the metal-insulator-semiconductor (MIS) structure and diode are introduced. Following this we will describe the physics behind four types of devices that all of us use everyday and which have collectively changed the world: transistors, light emitting diodes (LEDs), lasers and solid state memories. We will study the field effect transistor (FET) and describe metal-oxide-semiconductor-field-effect-transistor (MOSFET) technology, then introduce the light-emitting diode (LED) and the semiconductor injection laser. Following this we will cover the physics behind some of the most common memories used today: the dynamic random access memory (DRAM) and Flash memories. Some simple circuits using these solid-state elements will be covered if time permits. The course is specifically tailored for undergraduate students, however it is also appropriate for graduate students who have less exposure to device physics and would like to learn about the subject.

Instructor(s): Supratik Guha Terms Offered: Autumn

Prerequisite(s): PHYS 23400 or CMSC 12300 or CMSC 15200 or CMSC 16200

**MENG 33700. Quantum Computation. 100 Units.**

This course provides an introduction to the fundamentals of quantum information to students who have not had training in quantum computing or quantum information theory. Some knowledge of quantum mechanics is expected, including bra-ket notation and the time-dependent form of Schrodinger's equation. Students will learn how to carry out calculations and gain a fundamental grasp of topics that will include some or all of: entanglement, teleportation, quantum algorithms, cryptography, and error correction.

Instructor(s): Staff Terms Offered: Winter

Prerequisite(s): PHYS 22100 or equivalent

Equivalent Course(s): MENG 23700

**MENG 33800. Introduction to Nanofabrication. 100 Units.**

This class will cover the fundamentals of nanofabrication from a practical viewpoint, and will be very useful for graduate students planning on pursuing research involving semiconductor processing technology, as well as broader topics such as microelectromechanical systems (MEMS), quantum devices, optoelectronics and microfluidics. This class will cover the theory and practice of lithographic patterning; physical and chemical vapor deposition; reactive plasma etching; wet chemical processing; characterization techniques; and other special topics related to state-of-the-art processes used in research and development of nanoscale devices. A good grounding in introductory chemistry and physics is expected.

Instructor(s): Staff Terms Offered: Winter

Prerequisite(s): PHYS 13300 and CHEM 10200 or equivalent.

**MENG 34100-34200. Selected Topics in Molecular Engineering: Molecular/Materials Modelling I-II.**

Molecular modeling seeks to develop models and computational techniques for prediction of the structure, thermodynamic properties, and non-equilibrium behaviour of gases, liquids, and solids from knowledge of intermolecular interactions.

**MENG 34100. Selected Topics in Molecular Engineering: Molecular/Materials Modelling I. 100 Units.**

This course will introduce students to the methods of molecular modeling. The topics covered will include an introduction to the origin of molecular forces, a brief introduction to statistical mechanics and ensemble methods, and an introduction to molecular dynamics, Brownian dynamics, and Monte Carlo simulations. The course will also cover elements of advanced sampling techniques, including parallel tempering, umbrella sampling, and other common biased sampling approaches. Course work or research experience is strongly recommended in: (1) elementary programming (e.g., C or C++), and (2) physical chemistry or thermodynamics.

Instructor(s): Juan de Pablo, Giulia Galli Terms Offered: Winter

Prerequisite(s): MATH 20000 and MATH 20100 or MATH 22000 or PHYS 22100

Equivalent Course(s): MENG 24100

**MENG 34200. Selected Topics in Molecular Engineering: Molecular/Materials Modelling II. 100 Units.**

This course provides a continuation of the topics covered in Molecular/Materials Modelling I. It seeks to introduce students to electronic structure methods for modelling molecular and condensed systems. The topics covered will include an introduction to quantum mechanical descriptions of ground and excited state properties of molecules and solids. The course will focus on simulations based on the numerical solution of the Schrödinger equation using different approximations, including wavefunctions methods (e.g., Hartree Fock) and density functional theory, and various integration techniques and basis sets.

Instructor(s): Giulia Galli, Juan de Pablo Terms Offered: Spring

Prerequisite(s): MENG 24100

Equivalent Course(s): MENG 24200

**MENG 34300. The Engineering and Biology of Tissue Repair. 100 Units.**

This course will examine the biomolecular and cellular bases for tissue engineering, including biological processes and biomolecular actors underlying morphogenesis and tissue repair in a number of tissue systems. Biomaterials and drug release principles being developed for tissue engineering will be examined, and the means by which molecular engineering is interfaced with the biomolecules and cells involved in tissue morphogenesis for tissue engineering will be elaborated. Selected case studies in different tissue engineering applications will be considered both through didactic presentations and projects undertaken by the students.

Instructor(s): Joel Collier, Jeffrey Hubbell Terms Offered: Spring

Prerequisite(s): Coursework or research experience in cell biology and biochemistry strongly recommended.

**MENG 34310. Cellular Engineering. 100 Units.**

Cellular engineering is a field that studies cell and molecule structure-function relationships. It is the development and application of engineering approaches and technologies to biological molecules and cells. This course is intended to be a bridge between engineers and biologists, to quantitatively study cells and molecules and develop future clinical applications. Topics include fundamental cell and molecular biology; immunology and biochemistry, receptors, ligands, and their interactions; nanotechnology/biomechanics; enzyme kinetics; molecular probes; cellular and molecular imaging; single-cell genomics and proteomics; genetic and protein engineering; and drug delivery and gene delivery.

Instructor(s): Jun Huang Terms Offered: Winter

Prerequisite(s): Completion of first three quarters of Biological Fundamentals Sequence.

Equivalent Course(s): MENG 24310, BIOS 21508

**MENG 34500. Microfluidics and Its Applications. 100 Units.**

Precision control of fluids at the micrometer scale (hence microfluidics) provides unprecedented capabilities in manipulation and analysis of cells and proteins. Moreover, fluids and particles behave in fundamentally different ways when confined to small dimensions, making microfluidics an interesting topic of basic research. This course aims to provide students with theoretical knowledge and practical skills on the use of microfluidics for the manipulation and analysis of physical, chemical and biological systems. We will first survey theoretical concepts regarding microfluidics. We will then focus on design considerations and fabrication methods for multi-layer microfluidic chips using PDMS soft-lithography. We will learn how to fabricate, multiplex and control PDMS membrane valves and integrate them into high-throughput analytical systems. We will survey recent developments in microfluidics and its scientific and industrial applications. Biological systems analysis in cell sorting, culture, cell signaling, single molecule detection, digital nucleic acid and protein quantification, and biosensing are some of the applications we will cover. This course will have a Laboratory component where students will design, fabricate and use microfluidic devices and therefore acquire hands-on skills in microfluidic engineering.

Instructor(s): Savas Tay Terms Offered: Spring

Prerequisite(s): This course is open to graduate students from all STEM fields; undergraduates must have completed three quarters of a Biological Sciences Fundamentals Sequence or MENG 26202 or CHEM 26200 or PHYS 23500.

**MENG 34600. Quantitative Systems Biology. 100 Units.**

This course aims to provide students with knowledge on the use of modern methods for the analysis, manipulation and modeling of complex biological systems, and to introduce them to some of the most important applications in quantitative and systems biology. We will first survey theoretical concepts and tools for analysis and modeling of biological systems like biomolecules, gene networks, single cells and multicellular systems. Concepts from information theory, biochemical networks, control theory and linear systems will be introduced. Mathematical modeling of biological interactions will be discussed. We will then survey quantitative experimental methods currently used in systems biology. These methods include single cell genomic, transcriptomic and proteomic analysis techniques, *in vivo* and *in vitro* quantitative analysis of cellular and molecular interactions, single molecule methods, live cell imaging, high throughput microfluidic analysis, and gene editing. Finally, we will focus on case studies where the quantitative systems approach made a significant difference in understanding of fundamental phenomena like signaling, immunity, and development, and diseases like infection, autoimmunity, and cancer.

Instructor(s): Savas Tay Terms Offered: TBD, Winter

**MENG 36300. Transport Phenomena. 100 Units.**

This course covers essential aspects of molecular transport processes, including fluid dynamics, mass transport and diffusion processes, and energy and heat transport processes. It also discusses the coupling that arises between momentum, mass and energy transport processes.

Instructor(s): Staff Terms Offered: Autumn

**MENG 37100. Biological Materials. 100 Units.**

The science and engineering of biological materials will be explored from both fundamental and translational perspectives. The materials science of naturally-occurring biological materials will be presented, including for natural inorganic materials such as hydroxyapatite in bone and calcium carbonate in marine shells, for natural polysaccharides, for natural structural proteins, and for lipid membranes. The materials science of synthetic materials used in biological and biomedical applications will be presented, with a focus on polymeric and bio polymeric systems, but touching also on metals and ceramics.

Instructor(s): Jeffrey Hubbell Terms Offered: Autumn

**MENG 37200. Electronic and Quantum Materials for Technology. 100 Units.**

This is a one quarter introductory course on the science and engineering of electronic and quantum materials. The intended audience is upper level undergraduate students and first year graduate students in Molecular Engineering and other related fields, including Chemistry and Physics. We will learn the basics of electrical and optical properties of electronic materials, including semiconductor, metal, and insulators starting from a simple band picture and discuss how these materials enable modern electronic and optoelectronic devices and circuitry. We will also explore the modern synthesis techniques for these materials and the effects of reduced dimensions and emergent quantum properties. No comprehensive exposure to quantum mechanics, thermodynamics or advanced mathematical skills will be assumed, even though working knowledge of these topics will be helpful.

Instructor(s): Jiwoong Park Terms Offered: Spring

**MENG 40000. First-Year Graduate Research Colloquium. 000 Units.**

Aimed both at nurturing the highly interdisciplinary environment of the IME and at supporting first-year students in their selection of research advisors, this weekly seminar surveys the research interests and projects of IME faculty and fellows. Required for all first-year Molecular Engineering graduate students.

Instructor(s): Staff Terms Offered: Autumn

Prerequisite(s): Required for all first-year Molecular Engineering graduate students.

**MENG 49900. Research: Molecular Engineering. VAR Units.**

No description available.

Instructor(s): Staff Terms Offered: Summer, Autumn, Winter, Spring

**MENG 58001. Numerical Methods. 100 Units.**

This is a practical programming course focused on the basic theory and efficient implementation of a broad sampling of common numerical methods. Each topic will be introduced conceptually followed by detailed exercises focused on both prototyping (using matlab) and programming the key foundational algorithms efficiently on modern (serial and multicore) architectures. The ideal student in this course would have a strong interest in the use of computer modeling as predictive tool in a range of disciplines -- for example risk management, optimized engineering design, safety analysis, etc. The numerical methods studied in this course underlie the modeling and simulation of a huge range of physical and social phenomena, and are being put to increasing use to an increasing extent in industrial applications. After successfully completing this course, a student should have the necessary foundation to quickly gain expertise in any application-specific area of computer modeling.

Instructor(s): Andrew Siegel Terms Offered: Spring

Prerequisite(s): MPCS 50101 or programming waiver

Note(s): Non-MPCS students must receive approval from program prior to registering.





#### Font Notice

This document should contain certain fonts with restrictive licenses. For this draft, substitutions were made using less legally restrictive fonts. Specifically:

Times was used instead of Trajan.

Times was used instead of Palatino.

The editor may contact Leepfrog for a draft with the correct fonts in place.