# NanoEngineering (NANO)

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## Professional Research Staff

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# Departmental Focus

The Department of NanoEngineering focuses on nanoscale science, engineering, and technology that have the potential to make valuable advances in different areas that include, to name a few, new materials, biology and medicine, energy conversion, sensors, and environmental remediation. Nanoengineering is a highly diversified and multidisciplinary field. The graduate research programs cover a broad range of topics, but focus particularly on biomedical nanotechnology, nanotechnologies for energy conversion and storage, computational nanotechnology, and molecular and nanomaterials. Undergraduate degree programs focus on integrating the various science and engineering disciplines necessary for successful careers in the evolving nanotechnology industry.

# Undergraduate Programs

## *Degree and Program Options*

The Department of NanoEngineering offers undergraduate programs leading to the **B.S. degrees** in **nanoengineering** and **chemical engineering**. The Chemical Engineering program is accredited by the Engineering Accreditation Commission of the Accreditation Board of Engineering and Technology (ABET/EAC). The NanoEngineering program is newly introduced, but the program is designed using ABET accreditation criteria; the Department will apply for accreditation once there are graduates to measure the program outcomes. These two degree programs have very different requirements and are described in separate sections.

### *Policies and Procedures for Undergraduate Students*

#### Application for Admission to the Major

Admission to the department as a NANO or CENG major or minor, or to fulfill a major in another department which requires NANO or CENG courses, is in accordance with the general requirements established by the Jacobs School of Engineering. The admission requirements and procedures are described in detail in the section on “Admission to the Jacobs School of Engineering” in this catalog. Applicants who have demonstrated excellent academic performance prior to being admitted to UCSD will be admitted directly to the engineering major of their choice. These directly admitted students and all students are expected to complete lower- and upper-division courses, as suggested in the curriculum tables, in a timely fashion in the sequences outlined.

### *Academic Advising*

Upon admission to the major, students should consult the catalog or NanoEngineering Website (http://nanoengineering.ucsd.edu) for their program of study or their undergraduate/graduate advisor if they have questions. The program plan may be revised in subsequent years, but revisions involving curricular requirements require approval by the student affairs advisor or the Undergraduate/Graduate Affairs Committee. Because some course and/or curricular changes may be made every year, it is imperative that students consult with the department's student affairs advisor on an annual basis.

As aforementioned, NANO and CENG courses are offered only once a year and therefore should be taken in the recommended sequence. If courses are taken out of sequence, it may not always be possible to enroll in courses as desired or needed. If this occurs, students should seek immediate departmental advice. When a student deviates from the sequence of courses specified for each curriculum in this catalog, it may be impossible to complete the major within the normative four-year period.

In addition to the advising available through the Student Affairs Office, programmatic or technical advice may be obtained from faculty members. A specific faculty mentor is assigned to each student. All students are required to meet with their faculty mentor at least once a quarter.

### *Program Alterations/Exceptions to Requirements*

Variations from or exceptions to any program or course requirements are possible only if the Undergraduate Affairs Committee approves a petition before the courses in question are taken. Petition forms may be obtained from the Student Affairs Office and must be processed through this office.

### *Independent Study*

Students may take NANO 199 or CENG 199, Independent Study for Undergraduates, under the guidance of a NANO or CENG faculty member. This course is taken as an elective on a P/NP basis. Under very restrictive conditions, however, it may be used to satisfy upper-division technical elective course requirements for the major. Students interested in this alternative must identify a faculty member with whom they wish to work and propose a two-quarter research or study topic. After obtaining the faculty member's concurrence on the topic and scope of the study, the student must submit a Special Studies Course form (each quarter) and NANO 199 or CENG 199 as Technical Elective Contract form to the Undergraduate Affairs Committee. These forms must be completed, approved, and processed prior to the add/drop deadline. Detailed policy in this regard and the requisite forms may be obtained from the Student Affairs Office.

## *Transfer Students*

The undergraduate engineering curriculum is designed to integrate four years of college educational experience. It is not easy for transfer students to complete the major requirements in only two additional years beyond their junior college work. Students should consult their advisor for a transition program compatible with their junior college preparation.

Requirements for admission as a NANO or CENG major or into NANO or CENG courses are the same for transfer students as they are for continuing students (see section on "Admission to the Jacobs School of Engineering" in this catalog). Accordingly, when planning their program, transfer students should be mindful of lower-division prerequisite course requirements, as well as for meeting collegiate requirements.

Students who have taken equivalent courses elsewhere may request to have transfer credit apply toward the department's major requirements. To receive transfer credit, complete a Student Petition form and submit it to Student Affairs. For mathematics, chemistry and physics, the respective department determines transfer equivalencies. An Undergraduate Student Petition must be submitted to each department from which you are requesting transfer credit.

The following courses are *strongly recommended for all engineering transfer students* for success in their major.

- Calculus I—for Science and Engineering (Math. 20A)
- Calculus II—for Science and Engineering (Math. 20B)
- Calculus and Analytic Geometry (Math. 20C)
- Differential Equations (Math. 20D)
- Linear Algebra (Math. 20F)
- Complete calculus-based physics series with lab experience (Physics 2A-B-C)
- Chemistry 6A (except computer science and computer engineering majors)
- Highest level of introductory computer programming language course offerings at the community college*
- Community college equivalent courses can be found at: http://www.assist.org

* Refer to the *UCSD General Catalog* to select major prerequisite recommendations for computer language courses.

## NanoEngineering Program Mission and Objectives

The mission of the NanoEngineering Program is to provide a multidisciplinary education in nanoscale science and technology. The primary goals are:

- Prepare students for a career in nanotechnology by providing them with a sound grounding in multidisciplinary areas of nanoscale science and engineering.
- Increase students' understanding of materials and their properties at the atomic and nanometer scales, including an understanding of the intimate relationship between the scale and the properties of materials. This is referred to as the third dimension in the periodic table, where elements, and combinations thereof, have properties and functions that depend on the material dimension, spanning from the nanoscale to macroscale.
- Prepare graduates who, while skilled in nanoscale science and engineering, will be qualified for jobs in traditional science-based industries and government laboratories and, as nanotechnologies mature, well positioned for jobs in this applied area. This program will be anticipating trends and providing students with integrated, cross-disciplinary scientific knowledge and professional skills.
- Educate a new generation of engineers who can participate in, and indeed seed, new high-technology companies that will be the key to maintaining jobs, wealth and educational infrastructures as nanotechnology results in a new industrial revolution.
- Enable students to develop a range of professional, scientific and computational skills that will enhance employment opportunities in a wide range of industrial and governmental institutions.
- Prepare students for the workplace through developing their ability to have effective communication skills, modern science and engineering skills, and contribute constructively to multidisciplinary teams.
- Form strong multidisciplinary educational links through joint team projects that cross the traditional areas of science and engineering.

## NanoEngineering Undergraduate Program

The B.S. program in NanoEngineering is tailored to provide breadth and flexibility by taking advantage of the strength of basic sciences and other engineering disciplines at UC San Diego. The intention is to graduate nanoengineers who are multidisciplinary and can work in a broad spectrum of industries.

All NANO courses are taught only once per year, and courses are scheduled to be consistent with the curriculum as shown in the tables below. Under normal circumstance, students must follow the prescribed curriculum. Unavoidable deviation from the curriculum, for example to participate in the Education Abroad Program, must be approved by the Undergraduate Affairs Committee prior to taking alternative courses elsewhere. Approvals are also needed for engineering courses not listed under the current selections for different engineering focus areas. Courses such as NANO 195, 197, and 198 are not allowed as a NanoEngineering elective in meeting the upper-division major requirements. NANO 199 can be used as a technical elective only under restrictive conditions. Policy regarding these conditions may be obtained from the department's Student Affairs Office. All students are encouraged to visit the Student Affairs Office or visit the Department of NanoEngineering Website for any clarification and updated information. To graduate, students must maintain an overall GPA of at least 2.0, and the department requires at least a C– grade in each course required for the major.

### General-Education/College Requirements

For graduation each student must satisfy general-education course requirements determined by the student's college as well as the major requirements determined by the department. The six colleges at UCSD require widely different general-education courses, and the number of such courses differs from one college to another. Each student should choose his or her college carefully, considering the special nature of the college and the breadth of general education.

The NANO curriculum allows for forty-eight units of humanities and social science (HSS) courses, which are sufficient to fulfill most but not all college requirements. Regardless of the specific college, students must develop a program that includes a total of at least forty-eight units in the arts, humanities, and social sciences, not including subjects such as accounting, industrial management, finance, or personnel administration. Students must consult with their college to determine which HSS courses to take.

## Major Requirements

To receive a B.S. in NanoEngineering, students must complete 192 units. The specific breakdown is as follows:

**Humanities and social sciences (forty-eight units):** This requirement is intended to fulfill the general-education requirements (GER) from respective colleges.

**Basic sciences and mathematics (fifty-nine units):** This lower-division requirement includes twenty-four units of mathematics (Math. 20A–F), sixteen units of physics (Phys 2A–D), fifteen units of chemistry (Chem 6A–C, 6BL), and four units of biology (BILD 1).

**Engineering Preparation (sixteen units):** This requirement covers basics in computer programming, circuit analysis and circuits lab (ECE 15, 25, 35, 65).

**Nanoengineering core (thirty-seven units):** This requirement is constituted of a one-unit seminar (NANO 1) and nine core courses (NANO 101 to 104, 110 to 112, and 120A-B).

**Nanoengineering electives (eight units):** This requirement must be chosen from among the upper-division NANO courses offered by the Department.

**Engineering Focus (twenty-four units):** Students are recommended to select all six engineering electives from within one single major to constitute an engineering focus. However, to allow for unforeseen class scheduling conflicts and to comply with the prerequisites of some Bioengineering courses, students are required to take only four of the six courses in one major, with the other two outside their chosen engineering focus. Preapproved accepted courses of each of the four focuses are listed below.

*Bioengineering:*
BENG 100, 101, 103B*, 109, 110, 112A, 112B, 122A*, 130, 186A
* BENG 103B requires CENG 101A and BENG 122A requires MAE 140. Both prerequisites are accepted as part of the 24-unit Bioengineering focus.

*Chemical engineering:*
CENG 100, 101A, 101B, 101C, 102, 113, 120

*Electrical engineering:*
ECE 103, 107, 109, 134, 135A, 135B, 136, 136L, 138L, 139, 183, 187

*Mechanical engineering:*
MAE 20, 101A, 101B, 101C, 105, 113, 110A, 130A, 130B, 131A, 143A, 143B, 160, 161, 166, 168

*Materials science:*
NANO 108, 140, 148, 150, 156, 158, 161, 164, 168

All students follow the same basic science preparation and core set of classes in NanoEngineering during the first two years.

| FALL | WINTER | SPRING |
|---|---|---|
| **FRESHMAN YEAR** | | |
| Math. 20A | Math. 20B | Math. 20C |
| Chem. 6A | Chem. 6B | Chem. 6C |
| ECE 15 | BILD 1 | Phys. 2A |
| HSS | HSS | HSS |
| | NANO 1 | |
| **SOPHOMORE YEAR** | | |
| Math. 20D | Math. 20F | Math. 20E |
| Phys. 2B | Phys. 2C | Phys. 2D |
| Chem 6BL | NANO 101 | ECE 25 |
| HSS | HSS | HSS |

After the sophomore year, students must choose an engineering focus. Sample programs of the five choices are shown below. Students must keep in mind that the NANO courses are only offered once a year.

**Recommended course sequence—Bioengineering focus**

| FALL | WINTER | SPRING |
|---|---|---|
| **JUNIOR YEAR** | | |
| NANO 102 | NANO 103 | NANO 104 |
| CENG 101A | BENG 130 | BENG 100 |
| ECE 35 | ECE 65 | NANO Elective |
| HSS | HSS | HSS |
| **SENIOR YEAR** | | |
| NANO 110 | NANO 111 | NANO 112 |
| BENG 101 | BENG 109 | BENG 103B |
| NANO Elective | NANO 120A | NANO 120B |
| HSS | HSS | HSS |

**Recommended course sequence—Chemical Engineering focus**

| FALL | WINTER | SPRING |
|---|---|---|
| **JUNIOR YEAR** | | |
| NANO 102 | NANO 103 | NANO 104 |
| CENG 100 | CENG 102 | CENG 113 |
| ECE 35 | ECE 65 | NANO Elective |
| HSS | HSS | HSS |
| **SENIOR YEAR** | | |
| NANO 110 | NANO 111 | NANO 112 |
| CENG 101A | CENG 101B | CENG 101C |
| NANO Elective | NANO 120A | NANO 120B |
| HSS | HSS | HSS |

**Recommended course sequence—Electrical Engineering focus**

| FALL | WINTER | SPRING |
|---|---|---|
| **JUNIOR YEAR** | | |
| NANO 102 | NANO 103 | NANO 104 |
| ECE 35 | ECE 65 | ECE 134 |
| ECE 103 | NANO Elective | ECE 136 |
| HSS | HSS | HSS |
| **SENIOR YEAR** | | |
| NANO 110 | NANO 111 | NANO 112 |
| ECE 135A | ECE 135B | ECE 139 |
| NANO Elective | NANO 120A | NANO 120B |
| HSS | HSS | HSS |

**Recommended course sequence—Mechanical Engineering focus**

| FALL | WINTER | SPRING |
|---|---|---|
| **JUNIOR YEAR** | | |
| NANO 102 | NANO 103 | NANO 104 |
| NANO 108 | MAE 130A | MAE 131A |
| ECE 35 | ECE 65 | MAE 130B |
| HSS | HSS | HSS |
| **SENIOR YEAR** | | |
| NANO 110 | NANO 111 | NANO 112 |
| CENG 101A | NANO 120A | NANO 120B |
| MAE 105 | NANO Elective | NANO Elective |
| HSS | HSS | HSS |

**Recommended course sequence—Materials Science focus**

| FALL | WINTER | SPRING |
|---|---|---|
| **JUNIOR YEAR** | | |
| NANO 102 | NANO 103 | NANO 104 |
| ECE 35 | ECE 65 | NANO 148 |
| NANO 108 | NANO Elective | NANO 150 |
| HSS | HSS | HSS |
| **SENIOR YEAR** | | |
| NANO 110 | NANO 111 | NANO 112 |
| NANO 158 | NANO 120A | NANO 120B |
| NANO 161 | NANO Elective | NANO 168 |
| HSS | HSS | HSS |

# Courses

## For course descriptions not found in the 2010-2011 General Catalog, please contact the department for more information.

### *COURSES IN NANOENGINEERING (NANO)*

All students enrolled in NANO courses or admitted to the NANO major are expected to meet Prerequisite and performance standards, i.e., students may not enroll in any NANO courses or courses in another department which are required for the major prior to having satisfied prerequisite courses with a C– or better. (The department does not consider D or F grades as adequate preparation for subsequent material.) Additional details are given under the program outline, course descriptions, and admission procedures for the Jacobs School of Engineering in this catalog.

## *LOWER-DIVISION*

**NANO 1. Nanoengineering Seminar (1)** Overview of nanoengineering. Presentations and discussions of basic knowledge and career opportunities in nanotechnology for professional development. Introduction to campus library resources. ***Prerequisites****: None.* (P/NP grading only.)

**NANO 87. Freshman Seminar (1)** The Freshman Seminar Program is designed to provide new students with the opportunity to explore an intellectual topic with a faculty member in a small seminar setting. Freshman seminars are offered in all campus departments and undergraduate colleges, and topics vary from quarter to quarter. Enrollment is limited to fifteen to twenty students, with preference given to entering freshman.

## *UPPER-DIVISION*

**NANO 101. Introduction to Nanoengineering (4)** Introduction to nanoengineering; nanoscale fabrication: nanolithography and self-assembly; characterization tools; nanomaterials and nanostructures: nanotubes, nanowires, nanoparticles, and nanocomposites; nanoscale and molecular electronics; nanotechnology in magnetic systems; nanotechnology in integrative systems; nanoscale optoelectronics; nanobiotechnology: biomimetic systems, nanomotors, nanofluidics, and nanomedicine. ***Prerequisites****: Grade of C- or better in Chem. 6B, Phys. 2B, Math. 20C.*

**NANO 102. Foundations in Nanoengineering A: Chemical Principles (4)** Chemical principles involved in synthesis, assembly, and performance of nanostructured materials and devices. Chemical interactions, classical and statistical thermodynamics of small systems, diffusion, carbon-based nanomaterials, supramolecular chemistry, liquid crystals, colloid and polymer chemistry, lipid vesicles, surface modification, surface functionalization, catalysis. ***Prerequisites****: Grade of C- or better in Chem. 6C, Math. 20D, NANO 101.*

**NANO 103. Foundations in Nanoengineering B: Biochemical Principles (4)** Principles of biochemistry tailored to nanotechnologies. The structure and function of biomolecules and their specific roles in molecular interactions and signal pathways. Detection methods at the micro and nano scales. ***Prerequisites****: Grade of C- or better in BILD 1, Chem. 6C, NANO 101.*

**NANO 104. Foundations in Nanoengineering C: Physical Principles (4)** Introduction to quantum mechanics and nanoelectronics. Wave mechanics, the Schröedinger equation, free and confined electrons, band theory of solids. Nanosolids in 0D, 1D, and 2D. Application to nanoelectronic devices. ***Prerequisites****: Grade of C- or better in Phys. 2D, Math. 20D, NANO 102.*

**NANO 108. Materials Science and Engineering (4)**
Structure and control of materials: metals, ceramics, glasses, semiconductors, polymers to produce useful properties. Atomic structures. Defects in materials, phase diagrams, micro structural control. Mechanical, rheological, electrical, optical and magnetic properties discussed. Time temperature transformation diagrams. Diffusion. Scale dependent material properties. ***Prerequisites****: NANO 101*

**NANO 110. Modeling of Nanoengineering Systems (4)** Engineering computation applied to nanotechnology: linear systems, nonlinear equations, optimization, solution of ordinary and partial differential equations, microfluidics simulation, quantum mechanical methods, Monte Carlo and molecular dynamics methods. Students will write programs and use open-source and commercial software. ***Prerequisites****: Grade of C- or better in Math. 20F, NANO 102, NANO 104.*

**NANO 111. Characterization of Nanoengineering Systems (4)** Fundamentals and practice of methods to image, measure and analyze materials and devices that are structured on the nanometer scale. Optical and electron microscopy; scanning probe methods; photon-, ion-, electron-probe methods, spectroscopic, magnetic, electrochemical and thermal methods. ***Prerequisites****: Grade of C- or better in NANO 102, NANO 103.*

**NANO 112. Synthesis and Fabrication of Nanoengineering Systems (4)** Introduction to methods for fabricating materials and devices in nanoengineering. Nano-particle, -vesicle, -tube and -wire synthesis. Top-down methods including chemical vapor deposition, conventional and advanced lithography, doping and etching. Bottom-up methods including self-assembly. Integration of heterogeneous structures into functioning devices. ***Prerequisites****: Grade of C- or better in NANO 102 and 103.*

**NANO 120A. Nanoengineering System Design I (4)** Principles of product design and the design process. Application and integration of technologies in the design and production of nanoscale components. Engineering economics. Initiation of team design projects to be completed in NANO 120B. ***Prerequisites****: Grade of C- or better in NANO 110, NANO 111.*

**NANO 120B. Nanoengineering System Design II (4)** Principles of product quality assurance in design and production. Professional ethics. Safety and design for the environment. Culmination of team design projects initiated in NANO 120A with a working prototype designed for a real engineering application. ***Prerequisites****: Grade of C- or better in NANO 120A.*

**NANO 140. Introduction to Molecular Simulations (4)** Principles of molecular simulations. The students will gain hands-on experience with development of a molecular dynamics and Monte Carlo codes, performing simulations, and analyzing simulation results. The students will also learn to apply molecular simulation techniques for solving nanoengineering problems. ***Prerequisites****: NANO 102, NANO 103, NANO 104.*

**NANO 143. Nanomedicine (4)** History of nanomedicine; length scale; main topics of nanomedicine: drug delivery, drugs and therapy, in vivo imaging, in vitro diagnosis, biomaterials, and active implants; nanomedicine in practice for disease treatment and diagnostics: cancers, cardiovascular diseases, immune diseases, and skin diseases. ***Prerequisites****: Department Stamp.*

**NANO 145. Introduction to Nanomachines (4)** Understanding nanoscale motion, scaling laws, motion control at the nanoscale, biological nanomotors, molecular nanomachines, design of artificial nanomotors, propulsion mechanisms of artificial nanomotors, applications and future opportunities and challenges. ***Prerequisites****: Department Stamp.*

**NANO 146. Nanoscale Optical Microscopy and Spectroscopy (4)** Fundamentals in optical imaging and spectroscopy at the nanometer scale. Diffraction-limited techniques, near-field methods, multi-photon imaging and spectroscopy, Raman techniques, Plasmon-enhanced methods, scan-probe techniques, novel sub-diffraction-limit imaging techniques, and energy transfer methods. ***Prerequisites****: NANO 101, NANO 102, NANO 103, NANO 104.*

**NANO 147. BioNanotechnology (4)** Introduction to biofabrication and bioengineering as applied to nanoscience and nanoengineering. Biological nanostructures, bioelectronics and biophysics. Basic biochemistry, genetic engineering and library screening techniques. Bioconjugation and characterization of biological systems on surfaces and nanoscale materials. Biological synthesis of inorganic nanocrystals. ***Prerequisites****: NANO 101, 102, 103, 104.*

**NANO 148. Thermodynamics of Materials (4)** Fundamental laws of thermodynamics for simple substances; application to flow processes and to non-reacting mixtures; statistical thermodynamics of ideal gases and crystalline solids; chemical and materials thermodynamics; multiphase and multicomponent equilibria in reacting systems; electrochemistry. ***Prerequisites****: NANO 101, NANO 102, NANO 103, NANO 104*.

**NANO 150. Mechanics of Nanomaterials (4)** Continuum, quantum and statistical mechanics, interatomic forces and intermolecular interactions, nanomechanics of self-assembly, pattern formation, hierarchical ordering, defects, surfaces, and interfaces, plasticity, creep, fracture and fatigue, adhesion, friction and wear, nanorheology, nanotribology, composite materials, carbon nanomaterials, biological materials. ***Prerequisites****: NANO 101*.

**NANO 156. Nanomaterials (4)** Basic principles of synthesis techniques, processing, microstructural control and unique physical properties of materials in nano-dimensions. Nanowires, quantum dots, thin films, electrical transport, optical behavior, functional behavior and technical applications of nanomaterials. ***Prerequisites****: Upper Division Standing*.

**NANO 158. Phase Transformations and Kinetics (4)** Materials and microstructures changes. Understanding of diffusion to enable changes in the chemical distribution and microstructure of materials, rates of diffusion. Phase transformations, effects of temperature and driving force on transformations and microstructure. ***Prerequisites****: NANO 101, NANO 102, NANO 103, NANO 104*.

**NANO 161. Material Selection in Engineering (4)** Selection of materials for engineering systems, based on constitutive analyses of functional requirements and material properties. The role and implications of processing on material selection. Optimizing material selection in a quantitative methodology. ***Prerequisites****: Department Stamp*.

**NANO 162. Nanosensors: Principles, Design and Applications (4)** Nanosensors based on different nanomaterials, fabrication of nanosensors, large-scale integration of nanosensor arrays, common recognition elements, surface chemistry and functionalization, signal transduction, practical applications. ***Prerequisites****: Department Stamp*.

**NANO 164. Advanced Micro- & Nano- Materials for Energy Storage and Conversion (4)** Materials for energy storage and conversion in existing and future power systems, including fuel cells and batteries, photovoltaic cells, thermoelectric cell and hybrids. ***Prerequisites****: Department Stamp*.

**NANO 168. Electrical, Dielectric, and Magnetic Properties of Engineering Materials (4)** Introduction to physical principles of electrical, dielectric and magnetic properties. Semiconductors, control of defects, thin film and nano-crystal growth, electronic and optoelectronic devices. Processing-microstructure-property relations of dielectric materials, including piezoelectric, pyroelectric and ferroelectric and magnetic materials. ***Prerequisites****: NANO 102, NANO 103, NANO 104*.

**NANO 192. Senior Seminar in NanoEngineering (1)** The Senior Seminar Program is designed to allow senior undergraduate to meet with faculty members in a small group setting to explore an intellectual topic in nanoengineering (at the upper division level). Topics will vary from quarter to quarter. Senior seminars may be taken for credit up to four times, with a change in topic, and permission of the department. Enrollment is limited to twenty students with preference given to seniors. ***Prerequisites****: Department Stamp or Consent of the Instructor.*

**NANO 195. Teaching (2-4)** Teaching and tutorial assistance in a NANO course under supervision of instructor. Not more than four units may be used to satisfy graduation requirements. ***Prerequisites****: Upper Division Standing and Department Stamp.* (P/NP Only).

**NANO 197. Engineering Internship (1-4)** Coordinated through UCSD Academic Internship Program, course provides work experience through industry, government offices, hospitals and their practices. Students work in local industry or hospital under faculty supervision. Units may not be applied toward major graduation requirements. Internship is unsalaried. ***Prerequisites****: Upper Division Standing and Department Stamp.*

**NANO 198. Directed Group Study (1-4)** Directed group study on a topic or in a field not included in the regular Department curriculum, by special arrangement with a Faculty member. ***Prerequisites****: Consent of Instructor.* (P/NP Only).

**NANO 199. Independent Study for Undergraduates (4)** Independent reading or research on a problem by special arrangement with a faculty member. ***Prerequisites****: Upper Division Standing and Department Stamp.* (P/NP Only).

# Chemical Engineering Program (CENG)

The Department of NanoEngineering is the administrative home of the interdepartmental Chemical Engineering Program (CENG).

## Professors

P. C. Chau, Ph.D., *NanoEngineering, Co-Director*
R.E. Continetti, Ph.D., *Chemistry and Biochemistry*
J.E. Crowell, Ph.D., *Chemistry and Biochemistry*
C. H. Gibson, Ph.D., *MAE*
D. A. Gough, Ph.D., *Bioengineering*
M. Krstic, Ph.D., *MAE*
A. C. Kummel, Ph.D., *Chemistry and Biochemistry*
J. Lasheras, Ph.D., *MAE*
J. McKittrick, Ph.D., *MAE*
B. O. Palsson, Ph.D., *Bioengineering*
K. Seshadri, Ph.D., *MAE*
J. B. Talbot, Ph.D., *NanoEngineering, Program Director*
J. Wang, Ph.D., *NanoEngineering*
F. A. Williams, Ph.D., *MAE*

## Professors Emeriti

S. Middleman, Ph.D., *MAE*
D.R. Miller, Ph.D., *MAE*

## Associate Professors

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R. K. Herz, Ph.D., *NanoEngineering*

## Assistant Professor

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J. Cha, Ph.D., *NanoEngineering*
A. Groisman, Ph.D., *Physics*
S. Meng, Ph.D., *NanoEngineering*
D. Sirbuly, Ph.D., *NanoEngineering*
A. Tao, Ph.D., *NanoEngineering*
L. Zhang, Ph.D., *NanoEngineering*

## Affiliated Faculty

L.A. Sung, Ph.D., *Associate Professor, Bioengineering*

# Chemical Engineering Undergraduate Program

## Degree and Program Options

**The B.S. program in chemical engineering (CENG)** is accredited by the Engineering Accreditation Commission of the Accreditation Board of Engineering and Technology (ABET/EAC).

## Program Objectives

The Chemical Engineering Program has affiliated faculty from the Department of NanoEngineering, Department of Mechanical and Aerospace Engineering, Department of Chemistry and Biochemistry, and the Department of Bioengineering. The curricula at both the undergraduate and graduate levels are designed to support and foster chemical engineering as a profession that interfaces engineering and all aspects of basic sciences (physics, chemistry, and biology).

The primary educational objectives of the Chemical Engineering Program are:

- To provide chemical engineering students with a strong technical education and communication skills that will enable them to have successful careers in a wide range of industrial and professional environments.
- To prepare chemical engineering students for rapidly changing technological environments with the core knowledge central to multidisciplinary development and personal improvement throughout their professional careers.
- To instill in chemical engineering students a strong sense of humanistic values and professionalism such that they can conduct ethically and knowledgeably regarding technological impact in societal issues.

The curriculum is designed to prepare chemical engineering graduates for further education and personal development through their entire professional career. We strive to accomplish these goals by providing a rigorous and demanding curriculum that incorporates lectures, discussions, laboratory and project development experiences in basic sciences, mathematics, engineering sciences, and design as well as the humanities and social sciences.

## The Chemical Engineering Undergraduate Program

The B.S. program in chemical engineering is accredited by the Engineering Accreditation Commission of the Accreditation Board of Engineering and Technology (ABET/EAC). The curriculum is tailored to provide breadth and flexibility by taking advantage of the strength of basic sciences and other engineering disciplines at UCSD. The intention is to graduate chemical engineers who are multidisciplinary and can work in a broad spectrum of industries rather than solely traditional chemical and petrochemical industries.

Areas of specialization are available whereby a graduate can be in a position for a career in nanotechnology, environmental technology, microelectronic device fabrication, materials and polymer processing, pharmaceutical and biotechnology, biomedical engineering, energy and thermal systems, control and system engineering, and so forth.

For students who aspire to pursue a graduate degree and a career in research and development, the units in an area of specialization can be allocated to more fundamental science and engineering courses. These students are also encouraged to perform independent projects in one of the faculty research laboratories or groups.

Whether the career goal is industry, or graduate or professional school, the curriculum has a strong emphasis on developing problem-solving skills and the ability to think and learn independently. The capstone courses are the senior design and process lab courses. Students learn to participate in project teams, refine their communication skills, and work on various design and experimental projects that over two quarters introduce them to elements of project planning, execution, analysis, and improvement.

Entering freshmen will follow the new set of course work guidelines detailed in this section. Continuing students will continue with their current set of course work guidelines outlined in previous general catalogs. The Student Affairs Office can provide the proper curriculum tables. All students are encouraged to visit the Student Affairs Office or visit the Department of NanoEngineering Web site for any clarification and updated information.

Deviations from these programs of study must be approved by the Undergraduate Affairs Committee prior to taking alternative courses. In addition, technical elective (TE) course selections must have departmental approval prior to taking the courses. The TE courses are restricted to meet ABET standards. Courses such as CENG 195, 197, and 198 are not allowed as a technical elective in meeting the upper-division major requirements. CENG 199 can be used as a technical elective only under restrictive conditions. Policy regarding these conditions may be obtained from the department’s Student Affairs Office. To graduate, students must maintain an overall GPA of at least 2.0, and the department requires at least a C– grade in each course required for the major.

Students with different academic preparation may vary the scheduling of lower-division courses such as math, physics and chemistry, but should consult the department. Deviations in scheduling CENG upper-division courses are discouraged and require prior approval. Most lower-division courses are offered more than once each year to permit students some flexibility in their program scheduling. However, all CENG upper-division courses are taught only once per year, and courses are scheduled to be consistent with the curricula as shown in the tables.

## General-Education/College Requirements

For graduation each student must satisfy general-education course requirements determined by the student’s college as well as the major requirements determined by the department. The six colleges at UCSD require widely different general-education courses, and the number of such courses differs from one college to another. Each student should choose his or her college carefully, considering the special nature of the college and the breadth of general education.

The CENG program allows for humanities and social science (HSS) courses so that students can fulfill their college requirements. As an ABET accredited program, students must develop a program that includes a total of at least twenty-four units in the arts, humanities, and social sciences, not including subjects such as accounting, industrial management, finance, or personnel administration. Students must consult with their college to determine which HSS courses to take.

## Professional Licensing

After graduation, all students are encouraged to take the Fundamentals of Engineering (FE) examination as the first step in becoming licensed as a professional engineer (PE). Students graduating from our accredited program can take the PE examination after FE certification and two years of work experience; students graduating from a non-accredited program can take the PE examination after FE certification and four years of work experience.

For further information please contact your local Board of Registration for Professional Engineers and Land Surveyors.

## Major Requirements

To receive a B.S. in chemical engineering, students must complete 194 units for graduation, which includes forty-four units of general education (HSS) requirements of their colleges and the ABET requirements in the arts, humanities, and social sciences. The balance consists of basic sciences (fifty-three units), chemistry core (twenty units), chemical engineering core (thirty-two units), process laboratory and design (sixteen units), general engineering (twelve units), and an area of specialization (sixteen units). Beyond the fifty-three units of basic sciences, the science and engineering courses total to ninety-six units. A one-unit introductory seminar (CENG1) is required of all incoming freshmen and transfer students. The specific breakdown is as follows:

### Basic sciences (fifty-three units):

This lower-division requirement includes twenty-four units of mathematics (Math. 20A–F), fourteen units of physics (Phys. 2A–C, 2CL), and fifteen units of chemistry (Chem. 6A–C, 6BL).

### Chemistry core (twenty units):

Five advanced chemistry electives must be selected from among Chem. 131, 132, 133, 140A-B, 114A-B, and 120 A-B, and 143A. Two recommended options are Chem. 140A-B, 114A-B, and 143A for those interested in biochemical/organic, and Chem. 131, 132, 133, 120A, and 140A for those interested in inorganic/materials.

### Chemical engineering core (thirty-two units):

This requirement covers chemical process modeling, solution thermodynamics, transport phenomena, chemical reaction engineering, process control, and unit operations (CENG 100, 101A–C, 102, 113, 120, 122).

### Process laboratory and design (sixteen units):

This requirement is crucial to fulfill the ABET design content (CENG 124A-B, 176A-B).

## General engineering (twelve units):

This requirement covers basics in computer programming, probability and statistics, and instrumentation. The computer programming requirement can be satisfied with a course in either Fortran (MAE 10), C (MAE 9), or Java (CSE 8B or 11). If you have no programming experience, you need CSE 8A before 8B, but no credit is given for 8A alone. Probability and statistics can be satisfied with ECE 109 or an approved course with equivalent content. Instrumentation is satisfied with MAE 170.

## Electives in an area of specialization (sixteen units):

Electives are intended to broaden and enhance professional goals. They may be chosen to achieve either breadth or depth in one's education. All electives must be upper-division courses in engineering. Suggestions are listed below.

### *Biotechnology/Biochemical Engineering:*

BENG 161A-B-C. (Requires petition with the Department of Bioengineering. Requires prerequisites including Chem. 114A-B.)

### *Electronic Materials:*

ECE 103, 134, 135A, 136, 136L, MAE 161.

### *Engineering Mechanics:*

MAE 130A-B, 131A, 160.

### *Engineering Science:*

MAE 105, 107, 140.

### *Environmental Engineering:*

MAE 124, 125A-B.

### *Materials Science:*

MATS 201A-B-C, 205A, 227.

### *Nanotechnology*

MAE 166, MAE 168, CENG 207, 208, 211, 212, 213, 214, 215

### *Process Control:*

ECE 101, 171A-B or MAE 140, MAE 143A-B.

### *Thermal Engineering and Systems:*

MAE 118A-B-C, 110B, 113.

### *Independent Research:*

CENG 199 as equivalent to a senior thesis can be approved as equivalent to two elective courses (eight units). Consult department Student Affairs Office for details.

### *Principles of Team Engineering:*

ENG 100/L a four-unit elective equivalent can be approved for completion of ENG 100 and ENG 100L. A second elective equivalent will only be approved with petition prior to additional ENG 100L engagement. There is no retroactive approval if you complete a second quarter of ENG 100L without prior petition.

## Chemical Engineering (ABET Accredited Program)

| Fall | Winter | Spring |
|---|---|---|
| **Freshman Year** | | |
| Math. 20A | Math. 20B | Math. 20C |
| Chem. 6A | Phys. 2A | Phys. 2B |
| MAE 9[1] | Chem. 6B | Chem. 6C/6BL |
| HSS[2] | CENG 1 | HSS |
| | HSS | |
| **Sophomore Year** | | |
| Math. 20D | Math. 20F | Math. 20E |
| CENG 100 | CENG 102 | CENG 113 |
| Phys. 2C/2CL | Adv. Chem.[3] | Adv. Chem. |
| HSS | HSS | HSS |
| **Junior Year** | | |
| CENG 101A | CENG 101B | CENG 101C |
| MAE 170 | ECE 109[4] | AS[5] |
| Adv. Chem. | Adv. Chem. | Adv. Chem. |
| HSS | HSS | HSS |
| **Senior Year** | | |
| CENG 120[6] | CENG 124A | CENG 124B |
| CENG 122 | CENG 176A | CENG 176B |
| AS | AS | AS |
| HSS | HSS[7] | HSS |

[1] MAE 9 can be replaced by MAE 10, CSE 8B or 11.

[2] Humanities and social sciences (HSS).

[3] Five advanced chemistry electives must be selected from among Chem. 131, 132, 133, 140AB, 114A-B, and 120 A-B, and 143A. Two recommended options are Chem. 140A-B, 114A-B, and 143A for those interested in biochemical/organic, and Chem. 131, 132, 133, 120A, and 140A for those interested in inorganic/materials.

[4] The approved equivalent courses for ECE 109 are Math 183, Math 186, Math 181A (Math 180A is a prerequisite), ECON 120A and BIEB 100 (BILD 3 is a prerequisite).

[5] The electives in an area of specialization (AS) must be upper-division or graduate courses in engineering, based on the pre-approved sequences. Otherwise, the selections must receive prior approval of the department to meet ABET standards.

[6] If a student chooses process control as the area of specialization, CENG 120 can be replaced by a relevant course within the approved set of courses for specialization in process control.

[7] If students do not require these additional HSS courses to meet their college requirements, they may substitute an unrestricted elective in order to meet the minimum 194 unit graduation requirement. The twelfth HSS course is intended only for students who have additional college requirements to fulfill. To meet ABET requirements, students must have up to twenty-four units in the arts, humanities, and social sciences, not including subjects such as accounting, industrial management, finance, and personnel administration.

## Transfer Students

| Fall | Winter | Spring |
|---|---|---|
| **Junior Year** | | |
| Adv. Chem. | CENG 1<br>Adv. Chem. | Adv. Chem. |
| CENG 101A | CENG 101B | CENG 101C |
| CENG 100 | CENG 102 | CENG 113 |
| MAE 170 | ECE 109[1] | |

[1] Transfer students can petition with an equivalent course in probability and statistics if it is available at a junior college.

# Graduate Program

## Degree and Program Options

Plans are currently underway to develop graduate curricula leading to the **M.S. and Ph.D. degrees in nanoengineering by 2011.** Until nanoengineering graduate programs are in place, students wishing to pursue nanoengineering as a graduate focus are encouraged to apply to related graduate programs in bioengineering, chemical engineering, and mechanical and aerospace engineering. Transfer to nanoengineering will be considered upon approval of its degree programs.

The Chemical Engineering Program offers graduate instruction leading to the **M.S. and Ph.D. degrees in chemical engineering.** Effective fall 2009, Chemical Engineering will offer a concentration in nanotechnology within the graduate program, which also will bridge with the future graduate degree program in nanoengineering.

## Program Objectives

The Chemical Engineering Program has affiliated faculty from the Department of NanoEngineering, Department of Mechanical and Aerospace Engineering, Department of Chemistry and Biochemistry, and the Department of Bioengineering. The curricula at both the undergraduate and graduate levels are designed to support and foster chemical engineering as a profession that interfaces engineering and all aspects of basic sciences (physics, chemistry, and biology).

The primary educational objectives of the Chemical Engineering Program are:

- To provide chemical engineering students with a strong technical education and communication skills that will enable them to have successful careers in a wide range of industrial and professional environments.
- To prepare chemical engineering students for rapidly changing technological environments with the core knowledge central to multidisciplinary development and personal improvement throughout their professional careers.
- To instill in chemical engineering students a strong sense of humanistic values and professionalism such that they can conduct ethically and knowledgeably regarding technological impact in societal issues.

The curriculum is designed to prepare chemical engineering graduates for further education and personal development through their entire professional career. We strive to accomplish these goals by providing a rigorous and demanding curriculum that incorporates lectures, discussions, laboratory and project development experiences in basic sciences, mathematics, engineering sciences, and design as well as the humanities and social sciences.

## B.S./M.S. Contiguous Program

A contiguous program leading to a bachelor of science and a master of science degree in chemical engineering is offered to a student with junior standing who has an upper-division GPA of 3.5 or better and a 3.0 overall UCSD GPA. During the last quarter of their junior year (more specifically, the fourth quarter prior to the receipt of the B.S. degree), students interested in obtaining the M.S. degree within one year following receipt of the B.S. degree may apply to the department for admission to the program.

The M.S. program is intended to extend and broaden an undergraduate background and/or equip practicing engineers with fundamental knowledge in their particular fields. The degree is offered under both the Thesis Plan I and the Comprehensive Examination Plan II.

## Graduate Program

The Chemical Engineering Program offers graduate instruction leading to the M.S. and Ph.D. degrees in chemical engineering. The nanotechnology concentration signifies that four elective courses are chosen from the approved courses in this area.

Admission is in accordance with the general requirements of the graduate division, which requires at least a B.S. In some branch of engineering, sciences, or mathematics; an overall GPA of 3.0, and three letters of recommendation from individuals who can attest to the academic or professional competence and to the depth of their interest in pursuing graduate study.

In addition, all applicants are required to submit GRE General Test Scores. A minimum score of 550 on the Test of English as a Foreign Language (TOEFL) is required of all international applicants whose native language is not English. Students who score below 600 on the TOEFL are strongly encouraged to enroll in an English as a second language program before beginning graduate work. UC San Diego Extension offers an excellent English language program during the summers as well as the academic year.

Applicants are judged competitively. Based on the candidate's background, qualifications, and goals, admission to the program is in one of three categories: M.S. only, M.S., or Ph.D. Admission to the M.S. only category is reserved for students for whom the M.S. degree is likely to be the terminal graduate degree. The M.S. designation is reserved for students currently interested in obtaining an M.S. degree but who at a later time may wish to continue in the doctoral degree program. Admission to the Ph.D. Program is reserved for qualified students whose final aim is a doctoral degree.

Non-matriculated students are welcome to seek enrollment in graduate-level courses via UC Extension's concurrent registration program, but an extension student's enrollment in a graduate course must be approved by the instructor.

## Master's Degree Program

The M.S. Program is intended to extend and broaden an undergraduate education with fundamental knowledge in different fields. The degree may be terminal, or obtained on the way to the Ph.D. The degree is offered under both the Thesis Plan I and the Comprehensive Examination Plan II.

**M.S. Time Limit Policy:** Full-time M.S. students are permitted seven quarters in which to complete all requirements. While there is no written time limit for part-time students, the department has the right to intervene and set individual deadlines if it becomes necessary.

**Course requirements:** All M.S. students must complete a total of forty-eight units, which include a core of five courses (twenty units) chosen among fluid dynamics (CENG 210A, MAE 210B), heat and mass transfer (CENG 221AB), kinetics (CENG 252), and mathematics. To maintain a certain balance in the core, no more than two mathematics courses should be chosen among the choices of applied mathematics (MAE 294AB or Math. 210AB) and numerical mathematics (MAE 290AB or Math. 270AB).

No more than three courses (twelve units) of upper-division courses may be applied toward the total course work requirement. No more than a total of eight units of CENG 296 and 298 may be applied toward the course work requirement. Units in seminars (CENG 259) may not be applied toward the degree requirement.

**Thesis Plan I:** Completion of the research thesis (CENG 299) fulfills twelve units toward the total graduation requirement. The balance is made up of the five core courses (twenty units) and additional four elective courses (sixteen units) subject to the restrictions described above. The nanotechnology concentration signifies that four elective courses are chosen from the approved courses in this area.

**Comprehensive Examination Plan II:** This plan involves course work only and culminates in an oral comprehensive examination based on topics selected from the core courses. In addition to the five core courses (twenty units), one must choose an additional seven electives (twenty-eight units) subject to the restrictions of CENG 259, 296, and 298 described above. Sample electives are listed in the table below. A student should consult his or her academic advisor to choose an appropriate course schedule, including alternatives in bioengineering, electrical and computer engineering, materials science, basic sciences, and mathematics. The nanotechnology concentration signifies that four elective courses are chosen from the approved courses in this area.

| **Fall** | **Winter** | **Spring** |
|---|---|---|
| **Core selections** | | |

| | | |
|---|---|---|
| CENG 210A | CENG 221A | CENG 221B |
| MAE 290A or 294A | MAE 210B | CENG 252 |
| | MAE 290B or 294B | |

**Suggested electives**

| | | |
|---|---|---|
| MS 201A | MS 201B | MS 201C |
| MAE 211 | MAE 212 | MAE 213 |
| Math. 270A | Math. 270B | Math. 270C |
| Chem. 211 | Chem. 212 | Chem. 213 |

**Nanotechnology concentration**

| | | |
|---|---|---|
| CENG 211 | CENG 213 | |
| CENG 212 | CENG 214 | CENG 215 |

**Change of Degree:** Upon completion of the requirements for the M.S. degree, students admitted as M.S. only or M.S. candidates are not automatically eligible for admission to the Ph.D. Program.

M.S. only and M.S. candidates who subsequently wish to pursue a doctorate must submit an application for a change in status to their examining committee. The application, if approved by the committee, must be signed by a faculty member who expects to serve as the student's Ph.D. advisor. The student must also submit a general petition for graduate students to effect the change of status. If the student elects the comprehensive examination plan for the M.S. degree, the examining committee may recommend that the comprehensive examination may replace the preliminary qualifying examination expected of Ph.D. students.

## Doctoral Degree Program

The Ph.D. Program is intended to prepare students for a variety of careers in research and teaching. The emphasis is on research. In general, there are no formal course requirements. All students, in consultation with their advisors, develop appropriate course programs that will prepare them for the Preliminary Qualifying Examination and for their dissertation research. These programs must be planned to meet the time limits established to advance to candidacy and to complete the requirements of the degree.

All Ph.D. students are required to pass three examinations. The first is a Preliminary Qualifying Examination, which should be taken within three to four quarters of full-time graduate study. The second is the Ph.D. Qualifying Examination. The last is the Dissertation Defense.

**Preliminary Qualifying Examination:** The examination is intended to determine a candidate's basic understanding of engineering fundamentals and the candidate's ability to pursue successfully a research project at a level appropriate for the doctorate. The scope of the examination is based on topics selected from the core curriculum as listed under the M.S. degree program. A candidate is expected to demonstrate knowledge equivalent to these courses and formal enrollment record is not a prerequisite. The format is an oral examination administered by a committee of three faculty members in the Chemical Engineering Program. The candidate should present to the committee, prior to the examination, the five core courses that will constitute the basis of the examination.

**Depth Requirement:** A candidate must have the ability to perform in-depth analysis in the dissertation topic. A candidate should consult with the thesis advisor to develop a proper course program if it is deemed necessary. Depending on an individual's background and the nature of the research problem, a candidate should either complete a set of a minimum of four courses or demonstrate to the thesis advisor the equivalent knowledge and ability.

**Ph.D. Qualifying Examination:** Prior to taking this examination, the candidate must have completed the departmental qualifying examination, obtained a faculty research advisor, and must have made initial progress on a chosen dissertation project. At the time of application for advancement to candidacy, a doctoral committee responsible for the remainder of the student's graduate program is appointed by the Graduate Council under the policy listed in the "Graduate Studies" section of the *UC San Diego General Catalog*. The committee conducts the Ph.D. Qualifying Examination, during which the student must demonstrate the ability to engage in thesis research. The process involves the presentation of a plan for the thesis research project. The committee may ask questions directly or indirectly related to the project and general questions that it determines to be relevant. Upon successful completion of the examination, subject to the UCSD time limit policy, the student is advanced to candidacy and is awarded the candidate in philosophy degree (see "Graduate " section in this catalog).

**Teaching Experience:** Prior to the dissertation defense, the candidate must serve at least once as a teaching assistant with the responsibility to hold a problem-solving section one hour a week.

**Dissertation Defense:** This is the final Ph.D. examination. Upon completion of the dissertation research project, the candidate writes a dissertation that must be successfully defended in an oral examination and public presentation conducted by the doctoral committee. A complete copy of the student's dissertation must be submitted to each member of the doctoral committee four weeks before the defense. It is understood that this copy of the dissertation given to committee members will not be the final copy, and that the committee members may request changes in the text at the time of the defense. This examination may not be conducted earlier than three quarters after the date of advancement to doctoral candidacy. Acceptance of the dissertation by the Office of Graduate Studies and the University Librarian represents the final step in completion of all requirements for the Ph.D. degree.

**Ph.D. Time Limit Policy:** Pre-candidacy status is limited to four years. Doctoral students are eligible for university support for six years. The defense and submission of the doctoral dissertation must be within seven years.

**Annual Evaluation:** In the spring of each year, the faculty advisor evaluates each doctoral student's overall performance in course work, research, and prospects for financial support for future years. A written assessment is given to the student after the evaluation. If a student's work is found to be inadequate, the faculty may determine that the student cannot continue in the graduate program.

# Courses

*For course descriptions not found in the* UC San Diego General Catalog, 2010–11*, please contact the department for more information*.

# Courses in Chemical Engineering (CENG)

All students enrolled in CENG courses or admitted to the CENG program are expected to meet prerequisite and performance standards, i.e., students may not enroll in any CENG courses or courses in another department which are required for the major prior to having satisfied prerequisite courses with a C– or better. (The program does not consider D or F grades as adequate preparation for subsequent material.) Additional details are given under the program outline, course descriptions, and admission procedures for the Jacobs School of Engineering in this catalog.

# Lower-Division

**CENG 1. The Scope of Chemical Engineering (1)** Demonstrations and discussions of basic knowledge and the opportunities in chemical engineering for professional development. Introduction to campus library and computer resources. Use of personal software tools such as spread-sheeting and student edition of MATLAB. ***Prerequisites***: none. (P/NP grading only.)

# Upper-Division

**CENG 100. Process Modeling and Computation in Chemical Engineering (4)** Introduction to elementary numerical methods with applications to chemical engineering problems using a variety of problem solving strategies. Error analysis. Concepts of mathematical modeling, material and energy balances, and probability and statistics with applications to design problems. ***Prerequisites***: admission to the chemical engineering or bioengineering major only and grades of C– or better in MAE 9 or equivalent, and CHEM 6C or consent of instructor.

**CENG 101A. Introductory Fluid Mechanics (4)** Kinematics and equation of motion; hydrostatics; Bernoulli's equation; viscous flows; turbulence, pipe flow; boundary layers and drag in external flows; applications to chemical, structural, and bioengineering. Students may not receive credit for both MAE 101A and CENG 101A. ***Prerequisites***: admission to the major and grades of C– or better in PHYS 2A and MATH 20D, and 20E or consent of instructor.

**CENG 101B. Heat Transfer (4)** Conduction, convection, radiation heat transfer; design of heat exchangers. Students may not receive credit for both MAE 101C and CENG 101B. ***Prerequisites***: admission to the major and a grade of C– or better in CENG 101A.

**CENG 101C. Mass Transfer (4)** Diffusive and convective mass transfer in solids, liquids, and gases; steady and unsteady state; mass transfer coefficients; applications to chemical engineering and bioengineering. ***Prerequisites***: admission to the major and grade of C– or better in CENG 101A.

**CENG 102. Chemical Engineering Thermodynamics (4)** Thermodynamic behavior of pure substances and mixtures. Properties of solutions, phase equilibria. Thermodynamic cycles. Chemical equilibria for homogeneous and heterogeneous systems. ***Prerequisite***: grade of C– or better in CENG 100, and MATH 20D.

**CENG 113. Chemical Reaction Engineering (4)** Principles of chemical reactor analysis and design. Experimental determination of rate equations, design of batch and continuous reactors, optimization of selectivity in multiple reactions, consideration of thermal effects and residence time distribution. Introduction to multi-phase reactors. ***Prerequisite***: grade of C– or better in CENG 100 or consent of instructor and MATH 20D.

**CENG 120. Chemical Process Dynamics and Control (4)** Examination of dynamic linear and linearized models of chemical processes. Stability analysis. Design of PID controllers. Selection of control and manipulated variables. Root locus, Bode and Nyquist plots. Cascade, feed- forward and ratio controls. ***Prerequisite***: admission to the major and grades of C– or better in MATH 20D. (Students may not receive credit for both MAE 141A or MAE 143B and CENG 120.)

**CENG 122. Separation Processes (4)** Principles of analysis and design of systems for separation of components from a mixture. Topics will include staged operations (distillation, liquid-liquid extraction), and continuous operations (gas absorption, membrane separation) under equilibrium and nonequilibrium conditions. ***Prerequisites***: admission to the major and grades of C– or better in CENG 100, CENG 102, and CENG 101C.

**CENG 124A. Chemical Plant and Process Design I (4)** Principles of chemical process design and economics. Process flow diagrams and cost estimation. Computer-aided design and analysis. Representation of the structure of complex, interconnected chemical processes with recycle streams. Ethics and professionalism. Health, safety, and the environmental issues. ***Prerequisites***: admission to chemical engineering major and grades of C– or better in CENG 113 and CENG 122 or consent of instructor.

**CENG 124B Chemical Plant and Process Design II (4)** Engineering and economic analysis of integrated chemical processes, equipment, and systems. Cost estimation, heat and mass transfer equipment design and costs.

Comprehensive integrated plant design. Optimal design. Profitability. ***Prerequisites***: admission to chemical engineering major and grade of C– or better in CENG 124A.

**CENG 176A. Chemical Engineering Process Laboratory I (4)** Laboratory projects in the areas of applied chemical research and unit operations. Emphasis on applications of engineering concepts and fundamentals to solution of practical and research problems. ***Prerequisites***: admission to the major and grades of C– or better in CENG 113, CENG 122, and MAE 170 or consent of instructor and departmental approval.

**CENG 176B. Chemical Engineering Process Laboratory II (4)** Training in planning research projects, execution of experimental work and articulation (both oral and written) of the research plan and results in the areas of applied chemical technology and engineering operations related to mass, momentum, and heat transfer. ***Prerequisites***: admission to the major and grade of C– or better in CENG 176A.

**CENG 192. Senior Seminar in Chemical Engineering (1)** The Senior Seminar Program is designed to allow senior undergraduates to meet with faculty members in a small group setting to explore an intellectual topic in chemical engineering (at the upper division level). Topics will vary from quarter to quarter. Senior seminars may be taken for credit up to four times, with a change in topic, and permission of the department. Enrollment is limited to twenty students with preference given to seniors. ***Prerequisite***: department stamp or consent of the instructor.

**CENG 199. Independent Study for Undergraduates (4-4)** Independent reading or research on a problem by special arrangement with a faculty member. ***Prerequisite***: consent of instructor. (P/NP Only).

# Chemical Engineering Graduate Courses

**CENG 205. Graduate Seminar in Chemical Engineering (1)** Each graduate student in CENG is expected to attend one seminar per quarter, of his or her choice, dealing with current topics in chemical engineering. Topics will vary. ***Prerequisites***: None.

**CENG 207. Nanomedicine (4)** Introduction to nanomedicine; diffusion and drug dispersion; diffusion in biological systems; drug permeation through biological barriers; drug transport by fluid motion; pharmacokinetics of drug distribution; drug delivery systems; nanomedicine in practice: cancers, cardiovascular diseases, immune diseases, and skin diseases. ***Prerequisites***: None.

**CENG 208. Nanofabrication (4)** Basic engineering principles of nanofabrication. Topics include: photo-, electron beam and nanoimprint lithography, block copolymers and self-assembled monolayers, colloidal assembly, biological nanofabrication. ***Prerequisites***: None.

**CENG 210A. Fluid Mechanics I (4)** (Cross-listed with MAE 210A.) Basic conservation laws, flow kinematics. The Navier-Stokes equations and some of its exact solutions, non-dimensional parameters and different flow regimes, vorticity dynamics. ***Prerequisites***: MAE 101A-B and MAE 110A or consent of instructor.

**CENG 211. Introduction to Nanoengineering (4)** Understanding nanotechnology and broad implications; introduction to miniaturization: scaling laws; introduction to nanoscale physics: basics of quantum mechanics; nanomaterials: atom bonding and crystal structures; nanomechanical oscillators: motions and forces of beams and atoms; nanoelectronics: discussion of Fermi energy, quantum confinement, and single electron phenomena; nanoscale heat transfer: conduction, convection, and radiation; photonic properties of nanomaterials; major concepts of fluids and flow at the nanoscale; machinery of the cell and applications of nanobiotechnology. ***Prerequisites*:** None.

**CENG 212. Intermolecular and Surface Forces (4)** Development of quantitative understanding of the different intermolecular forces between atoms and molecules and how these forces give rise to interesting phenomena at the nanoscale, such as flocculation, wetting, self-assembly in biological (natural) and synthetic systems. ***Prerequisites*****:** None.

**CENG 213. Nanoscale Synthesis & Characterization (4)** Examination of nanoscale synthesis – top-down and bottom-up; physical deposition; chemical vapor deposition; plasma processes; sol-gel processing; soft-lithography; self-assembly & layer-by-layer; molecular synthesis. Nanoscale characterization; microscopy (optical and electron: SEM, TEM); scanning probe microscopes (SEM, AFM); profilometry; reflectometry & ellipsometry; x-ray diffraction; spectroscopies (EDX, SIMS, Mass spec, Raman, XPS); particle size analysis; electrical, optical, magnetic, mechanical, thermal. ***Prerequisites*****:** None.

**CENG 214. Nanoscale Physics & Modeling (4)** Expanded mathematical analysis of topics introduced in CENG 212. Introduction of both analytical and numerical methods through application to problems in nanoengineering. Nanoscale systems of interest include colloidal systems, block-copolymer based self-assembled materials, molecular motors made out of DNA, RNA, or proteins etc. Nanoscale phenomena including self-assembly at the nanoscale, phase separation within confined spaces, diffusion through nanopores and nanoslits etc. Modeling techniques include quantum mechanics, diffusion and kinetics theories, molecular dynamics etc. ***Prerequisites*****:** CENG 212 or consent of the instructor.

**CENG 215. Nanosystems Integration (4)** Discussion of scaling issues and how to carry out the effective hierarchical assembly of diverse molecular and nanoscale components into higher order structures which retain the desired electronic/photonic, structural, mechanical or catalytic properties at the microscale and macroscale levels. Novel ways to combine the best aspects of both top-down and bottom-up processes to create a totally unique paradigm change for the integration of heterogeneous molecules and nanocomponents into higher order structures. ***Prerequisites*****:** None.

**CENG 221A Heat Transfer (4)** (Cross-listed with MAE 221A.) Conduction, convection, and radiation heat transfer development of energy conservation equations. Analytical and numerical solutions to heat transport problems. Specific topics and applications vary. ***Prerequisites***: MAE 101A-B-C or CENG 101A-B-C or consent of instructor.

**CENG 221B Mass Transfer (4)** (Cross-listed with MAE 221B.) Fundamentals of diffusive and convective mass transfer and mass transfer with chemical reaction. Development of mass conservation equations. Analytical and numerical solutions to mass transport problems. Specific topics and applications will vary. ***Prerequisites***: MAE 101A-B-C or CENG 101A-B-C or consent of instructor.

**CENG 251. Thermodynamics (4)** Principles of thermodynamics of single and multi-component systems. Phase equilibria. Estimation, calculation, and correlation of properties of liquids and gases. ***Prerequisite***: consent of instructor.

**CENG 252. Chemical Reaction Engineering (4)** Analysis of chemical rate processes; complex kinetic systems. Chemical reactor properties in steady state and transient operations; optimal design policies. The interaction of chemical and physical transport processes in affecting reactor design and operating characteristics. Uniqueness/multiplicity and stability in reactor systems. Applications of the heterogeneous reactor systems. ***Prerequisite***: consent of instructor.

**CENG 253. Heterogeneous Catalysis (4)** Physics and chemistry of heterogeneous catalysis. Adsorption/desorption kinetics, chemical bonding, isotherms, kinetic models, selection of catalysts, poisoning, experimental techniques. ***Prerequisite***: consent of instructor.

**CENG 254. Biochemical Engineering Fundamentals (4)** Introduction to microbiology as relevant to the main topic, biological reactor analysis. Fermentation and enzyme technology. ***Prerequisite***: consent of instructor.

**CENG 255. Electrochemical Engineering (4)** Fundamentals of electrochemistry and electrochemical engineering. Structure of the double layer, cell potential and electrochemical thermodynamics, charge transfer kinetics, electrochemical transport phenomena, and introduction to colloidal chemistry. Applications such as corrosion prevention, electroplating, reactor design, batteries and fuel cells. ***Prerequisite***: consent of instructor.

**CENG 259. Seminar in Chemical Engineering (4)** Presentations on research progress by graduate students and by visitors from industrial and academic research laboratories. (May be repeated for credit. S/U grades only). ***Prerequisite***: consent of instructor.

**CENG 296. Independent Study in Chemical Engineering (4)** Independent reading or research on a problem as arranged by a faculty member. Must be taken for a letter grade only. ***Prerequisite***: consent of instructor.

**CENG 299. Graduate Research in Chemical Engineering (1-12)** S/U grades only. ***Prerequisite***: consent of instructor.

**CENG 501. Teaching Experience (2)** Teaching experience in an appropriate CENG undergraduate course under the direction of the faculty member in charge of the course. Lecturing one hour per week in either a problem-solving section or regular lecture. (S/U grades only) ***Prerequisites***: consent of instructor and departmental stamp.