CHEMICAL ENGINEERING

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Courtesy Professors: Steven Chu, Franklin M. Orr, Jr.
Lecturers: Kay Kanazawa, Anthony Pavone
Consulting Professors: James C. Mikkelsen, Jaan Noolandi, Conrad Schadt, Robert Schwaar, John Sinfelt, Do Yeung Yoon
Visiting Professor: Wolfgang Knoll
Visiting Associate Professor: Jürgen Rühe
Visiting Assistant Professor: Sophie Hamel de Monchenault

UNDERGRADUATE PROGRAM

BACHELOR OF SCIENCE

The Chemical Engineering depth sequence required for the B.S. degree (see the "School of Engineering" section of this bulletin) provides training in applied chemical kinetics, biochemical engineering, electronic materials, engineering thermodynamics, plant design, polymers, process analysis and control, separation processes, and transport phenomena. The B.S. program in Chemical Engineering additionally requires basic courses in biology, chemistry, engineering, mathematics, and physics.

There is no set B.S. program for Chemical Engineering students to follow. A sample program is available from the department's advisers, the Dean's Office in the School of Engineering, and at the *Handbook for Undergraduate Engineering Programs,* http://ughb.stanford.edu/index-js.html . It is recommended that the student discuss the prospective program with his or her adviser, especially if transferring from biology, chemistry, physics, or another field in engineering. With some advanced planning, the student can usually arrange to attend one of the overseas campuses.

For information about a Chemical Engineering minor, see the "School of Engineering" section of this bulletin.

GRADUATE PROGRAMS

The University's requirements for the M.S., Engineer, and Ph.D. degrees are outlined in the "Graduate Degrees" section of this bulletin.

MASTER OF SCIENCE

An M.S. program comprising an academic year of appropriate course work is available to accommodate students wishing to pursue a professional chemical engineering career after receiving the B.S. degree. The M.S. degree is awarded, without requiring a formal thesis, after a minimum of three quarters of broad study, subject to the specifications stated below.

Unit and Course Requirements—For students terminating their graduate work with the M.S. degree in Chemical Engineering, a program consisting of 42 units of academic work is required, including at least four lecture courses selected from the Chemical Engineering 200 to 400 lecture series. The remaining courses comprise all science or engineering graduate courses, and by petition to the Chair of the Department of Chemical Engineering, upper-division undergraduate courses in science and engineering. Credit toward the M.S. degree is not given for Chemical Engineering Special Topics courses numbered 500 to 512, or for the colloquium, 699. However, students must register for 699 and attend the colloquia.

Students wishing to obtain research experience should choose a research adviser and enroll in Chemical Engineering 600; up to 6 units may count toward the 42-unit requirement. Chemical Engineering 600, however, may not be substituted for any of the required four lecture courses in the Chemical Engineering 200 to 400 lecture series. A written report describing the results of this research must be submitted to and approved by the research adviser.

To ensure that an appropriately balanced program is taken by all M.S. candidates, the student's program must be approved by the graduate adviser, and a program proposal for the M.S degree should be developed by the student and adviser at their first meeting of the academic year.

Residency Requirement—See General Requirements in the "Graduate Degrees" section of this bulletin.

Minimum Grade Requirement—All courses intended to satisfy the 42-unit M.S. degree requirement must be taken for letter grades, if offered, and an overall grade point average (GPA) of 3.0 must be maintained.

ENGINEER

The degree of Engineer is awarded after completion of six quarters of study beyond the B.S degree, plus the requirements listed below. This degree is not required to enter the Ph.D. program.

Unit and Course Requirements—A minimum of 72 total units (including research) and 42 units of course work is required for the Engineer degree, including the following Chemical Engineering courses: 300, 310A, 310B, 340, 345, 350, 355, and one quarter of 370. The remaining courses, to total 42 units, may be chosen from the basic sciences and engineering according to the guidelines given in the Master of Science section above and with the consent of the graduate adviser. Students seeking the Engineer degree may apply for the M.S. degree once the requirements for that degree have been fulfilled (see above Master of Science section).

Residency Requirement—See General Requirements in the "Graduate Degrees" section of this bulletin.

Minimum Grade Requirement—All courses intended to satisfy the degree requirements must be taken for letter grades, if offered, and an overall grade point average (GPA) of 3.0 must be maintained.

Thesis Requirement—The thesis must represent a substantial piece of research equivalent to nine months of full-time effort and must be approved by a reading committee consisting of two members of the Chemical Engineering faculty.

Qualification for the Ph.D. Program by Students Receiving the Degree of Engineer—After completing all the requirements for the Engineer degree, a student may request to be examined on the Engineer research work for the purpose of qualifying for the Ph.D. If the request is granted, the student's thesis must be available in its final form for inspection by the faculty and must have been approved by the reading committee at least two weeks prior to the scheduled date of the examination.

DOCTOR OF PHILOSOPHY

The Ph.D. degree is awarded after completion of a minimum of nine quarters of study plus the requirements listed below.

Unit and Course Requirements—A minimum of 72 total units (including research) and 42 units of course work is required for the Ph.D. degree, including the following Chemical Engineering courses: 300, 310A, 310B, 340, 345, 350, 355, and one quarter of 370. In addition, two courses must be taken from one of the areas of concentration in the 440, 450, or 460 series. The remaining courses, to total 42 units, may be chosen from the basic sciences and engineering according to the guidelines given in the above Master of Science section and consent of the graduate adviser. Students seeking the Ph.D. degree may apply for the M.S. degree once the requirements for that degree have been fulfilled (see above Master of Science section).

Residency Requirement—See General Requirements in the Graduate Degrees section of this bulletin.

Minimum Grade Requirement—All courses intended to satisfy the degree requirements must be taken for letter grades, if offered, and an overall grade point average (GPA) of 3.0 must be maintained.

Teaching Requirement—All Ph.D. candidates, regardless of the source of their financial support, are required to gain teaching experience as an integral part of graduate training in the Department of Chemical Engineering.

Qualifying Examination—To be advanced to candidacy for the Ph.D. degree, the student must pass a preliminary qualifying examination. First-year students are asked to present orally and defend a critical review of a published paper before the faculty at the beginning of their first Spring Quarter. This examination is used to decide whether or not these students will be allowed to choose research advisers and begin thesis research in the Spring Quarter of their first year. Failing this examination leads to termination of the student's study towards the Ph.D. degree. It also precludes financial aid beyond that already promised. Under these circumstances, the student may apply for the M.S. degree once the requirements for that degree have been fulfilled (see above Master of Science section). Students passing this preliminary examination take a qualifying examination consisting of an oral defense of their research work before the faculty early in the Autumn Quarter of their second year.

Dissertation Requirement—A dissertation based on a successful investigation of a fundamental problem in chemical engineering is required; the student enrolls in Chemical Engineering 600 during the course of this research. In four to five calendar years after enrolling in the department, the student is expected to have fulfilled all the requirements for the Ph.D., including submission of a completed dissertation that has already been approved by his or her research adviser to the reading committee. No sooner than four weeks after this date, the student's University oral examination is scheduled. This exam, based on the candidate's dissertation research, is in the form of a public seminar followed by private questioning by an examining faculty committee. After satisfactory performance in the examination and submission of the dissertation to the Degree Progress, Office of the Registrar, the Ph.D. degree is awarded.

RESEARCH ACTIVITIES

Research investigations are currently being carried out in the following fields: applied statistical mechanics, biocatalysis, bioengineering, colloid science, computational materials science, electronic materials, hydrodynamic stability, kinetics and catalysis, Newtonian and non-Newtonian fluid mechanics, polymer science, rheo-optics of polymeric systems, and surface and interface science. Additional information may be found at the Department of Chemical Engineering website http://chemeng.stanford.edu .

FELLOWSHIPS AND ASSISTANTSHIPS

A number of fellowships and assistantships are awarded each year to incoming students. Application forms may be obtained from the department. The completed application must be received no later than January 15 preceding the start of the academic year for which the award is to be made.

COURSES

(WIM) indicates that the course meets the Writing in the Major requirements.

(AU) indicates that the course is subject to the University Activity Unit limitations (8 units maximum).

PRIMARILY FOR UNDERGRADUATES

20. Introduction to Chemical Engineering—(Enroll in Engineering 20.)

3 units, Spr (Robertson)

50Q. Stanford Introductory Seminar: Drug Delivery in the 21st Century—In the near future, medication will be delivered with highly engineered, controlled delivery systems. Such systems, currently available for motion sickness, heart pain, and high blood pressure, are developed by joining chemistry, biology, medicine, materials science, and engineering to design novel drug delivery devices. Students visit local companies where such devices are made. Guest scientists and engineers describe products on the market and in the pipeline. One sophisticated drug delivery system, the cigarette, is studied, learning about a technology that has created more harm than good; however, what we learn from it someday might form the basis for a therapeutic delivery system. Recommended: prior exposure to chemistry, physics, biology, mathematics, physiology.

3 units, Aut (Robertson, Rosen)

25. Biotechnology—(Enroll in Engineering 25.)

3 units, Aut (Robertson)

100. Chemical Process Modeling, Dynamics, and Control—Mathematical methods are applied to engineering problems, using chemical engineering examples. The development of mathematical models to describe chemical process dynamic behavior. Analytical and computer simulation techniques for the solution of ordinary differential equations. Dynamic behavior of linear first- and second-order systems. Introduction to process control. Dynamics and stability of controlled systems. Prerequisites: Mathematics 53 or 130, or Engineering 155A, or equivalent; Engineering 20.

3 units, Aut (Staff)

110. Equilibrium Thermodynamics—Thermodynamic properties, equations of state, properties of non-ideal systems including mixtures, and phase and chemical equilibria. Prerequisite: Chemistry 171.

3 units, Win (Madix)

120A. Fluid Mechanics—The flow of isothermal fluids from a momentum transport viewpoint. Continuum hypothesis, scalar fields, fluid statics, deformation of continuous media, non-Newtonian fluids, the equations of motion, creeping and potential flow, boundary layer theory, turbulence, free-surface phenomena, porous media flows. Prerequisites: junior standing in chemical engineering or consent of instructor; 100, and Mathematics 53 or Mathematics 130 or Engineering 155A, or equivalent.

4 units, Win (Shaqfeh)

120B. Energy and Mass Transport—The transport of energy and mass in solid and fluid continua. Fourier's law, heat transfer in solids, laminar flow, forced and free convection, boundary-layer heat transfer, natural convection with application to geophysical flows, energy transport by radiation, Fick's Law, binary diffusion, the equation of convective diffusion, mass transfer with chemical reaction, transport in turbulent flows, heat and mass transfer analogies. Prerequisite: 120A or equivalent.

4 units, Spr (Fuller)

130. Separation Processes—Analysis and design of equilibrium and non-equilibrium separation processes. Possible examples: distillation, liquid-liquid extraction, electrophoresis, centrifugation, chromatography, and reaction-assisted separation processes.

3 units, Spr (Musgrave)

140. Microelectronics Processing Technology—The chemistry and transport of microelectronics device fabrication. Introduction to solid state materials and electronic devices. Chemical processes including crystal growth, chemical vapor deposition, etching, oxidation, doping, diffusion, metallization, and plasma processing with emphasis on chemical, kinetic and transport considerations.

3 units, Spr (Bent)

150. Biochemical Engineering—The general principles used in the biological production of fine biochemicals, with an emphasis on biopharmaceuticals. Basic and applied principles in: enzyme kinetics, microbial physiology, recombinant DNA technology, metabolic engineering, fermentation media design, fermentor design, aseptic processing, fermentation process control and scale-up, product isolation, protein purification, protein folding, regulatory issues, and biochemical process cost modeling.

3 units, Aut (Swartz)

160. Polymer Science and Engineering—Introduction to polymer science, including free-radical and condensation polymerization, morphology of amorphous and semicrystalline polymers, linear viscoelasticity and rheology. Selected applications of polymers in information technology.

3 units, Win (Frank)

170. Kinetics and Reactor Design—Chemical kinetics, elementary steps, mechanisms, rate-limiting steps, and quasi-steady state approximations. Ideal isothermal and non-isothermal reactors; design principles. Multiplicity, ignition, and extinction in stirred tank reactors; limitations of thermodynamic equilibrium. Catalysis and catalytic reaction mechanisms. Chemical reactor models of animal digestion. Prerequisites: 110, 120A, 120B; Chemistry 171, 173.

3 units, Aut (Gast)

180. Chemical Engineering Plant Design—Open to seniors in chemical engineering or by consent of instructor. Application of chemical engineering principles to the design of practical plants for the manufacture of chemicals and related materials. Topics: flow-sheet development from a conceptual design, equipment design for distillation, chemical reactions, heat transfer, pumping, and compression; estimation of capital expenditures and production costs; plant construction.

3 units, Spr (Pavone)

185A,B. Chemical Engineering Laboratory—Investigation of the experimental aspects of chemical engineering science, emphasizing development of communications skills. Experiments illustrating lecture subjects are conducted by groups of students. Lab. (WIM)

185A. *3 units, Aut (Frank)*

185B. *3 units, Win (Klug)*

190. Undergraduate Research in Chemical Engineering—Lab or theoretical work for undergraduate students under the direct supervision of a faculty member. Research in one of the graduate research groups or other special projects in the undergraduate chemical engineering lab. Students should consult advisers for information on available projects.

(Staff)

PRIMARILY FOR GRADUATE STUDENTS

240. Microelectronic Processing Technology—See 140.

3 units, Spr (Bent)

250. Biochemical Engineering—See 150.

3 units, Aut (Swartz)

260. Polymer Science and Engineering—See 160.

3 units, Win (Frank)

300. Applied Mathematics in Chemical Engineering—Mathematical problems in transport phenomena, fluid mechanics, reactor design, quantum chemistry, and polymer science. Applications of tensor calculus, ordinary differential equations, linear eigenvalue problems, perturbation theory (regular and singular), topics in partial differential equations, Fourier transforms. Prerequisites: Mathematics 53, 113, 130; or Engineering 155A, Mathematics 131 or Engineering 155B, or equivalent.

3 units, Aut (Klug)

310A. Microscale Transport—Introduction to transport on small scales where macroscopic or bulk convective processes are unimportant. The basic equations of mass, momentum, and energy are derived for incompressible fluids. Local analysis based on the flow kinematics. Simplifications of these equations in the Stokes or creeping flow regime; solution techniques for these reduced sets of equations. Topics: Green's function or boundary integral solution methods, point particle solutions, rigid particulate motion in suspension, drop and bubble flows including thermocapillary motion, lubrication theory and the effective properties of composite media and suspensions; and time permitting, slender body theory and Brownian motion. Prerequisites: 120A, 120B, 300, or equivalents.

3 units, Win (Fuller)

310B. Connective Transport and Reaction Engineering—Continuation of 310A. Macroscale or convective transport of mass, momentum, and energy including chemical reaction from a fundamental perspective. Topics: inviscid flow theory and its coupling to mass, momentum, and energy boundary layers including free jets and wakes; boundary layers adjoining regions of constant circulation (e.g., drop flows) including Prandtl-Batchelor layers; convective mass transport with and without reaction, including Taylor-dispersion and generalized Graetz problems; the fundamentals for mass, momentum, and energy transport correlations. The concepts are applied to basic reaction engineering. Prerequisite: 310A or consent of the instructor.

3 units, Spr (Homsy)

340. Molecular Thermodynamics—Review of classical thermodynamics. Introduction to statistical thermodynamics; ensembles and partition functions. Application to phase equilibrium of solids and liquids, phase diagrams, and molecular dynamics simulation. Intermolecular forces and introduction to distribution functions, liquid state theory, integral equations, and perturbation theory. Chemistry 275 may be substituted.

3 units (Staff)

345. Spectroscopy and Applications of Quantum Mechanics—Development of theoretical approaches to spectroscopy, including spectroscopic transitions, transition probabilities, and selection rules. Photon and electron spectroscopies of the gas and solid phase. Topics: infrared, electron energy loss and Raman vibrational spectroscopies; Auger, x-ray and ultraviolet photoelectron spectroscopies; synchrotron-based spectroscopies including near edge x-ray absorption fine structure; basic nuclear magnetic resonance. Possible topics: solid state and computational methods. Prerequisite: Chemistry 271 or quantum mechanics.

3 units, Win (Bent)

350. Principles of Cellular Systems—Introduction to biological systems for engineering students. Emphasis is on viewing the cell as an integrated network of processes. Topics: what is the genome and how is it interpreted, how are cells organized spatially and energetically, protein catalysis, regulation of protein expression and other cellular processes, and new techniques in functional genomics. Biological Sciences 52 may be substituted.

3 units, Aut (Kao)

355. Advanced Biochemical Engineering—The technological tools for exploiting the power offered by modern biology. How a cell interacts with and influences its environment, how a production organism is optimized, what technology is used for large scale production, how products are isolated and purified, how proteins can be made without living cells, how a biopharmaceutical is formulated and delivered, and what the regulatory requirements are for drug approval and sale. Prerequisite: 350 or Biological Sciences 52, or equivalent.

3 units, Win (Swartz)

370A,B,C,D. Introduction to Chemical Engineering Research—One-quarter research projects (laboratory, library, or theoretical research) under the guidance of a faculty member. Findings are reported in a poster session for the entire department at the end of the quarter, with a written report to adviser.

3 units, Aut, Win, Spr, Sum (Staff)

440. Colloid and Interface Science—The fundamental physics and chemistry of the solid-liquid interface. The intermolecular, electrostatic, van der Waals, polymeric, and solvation forces governing colloidal behavior. Surface phenomena (wetting, spreading of thin films, and adsorption of macromolecules). Association colloids (micelles and microemulsions). Colloidal phase behavior and aggregation.

3 units, Spr (Gast)

442. Structure and Reactivity of Solid Surfaces—The structure of solid surfaces, including a description of experimental methods for determining the structures of single crystal surfaces. The adsorption of molecules on these surfaces, e.g., the thermodynamics of adsorption processes, surface diffusion, and the molecular structure of the adsorbates. Surface mediated reactions, i.e., heterogeneous catalysis, including descriptions of catalytic mechanisms and surface kinetics.

3 units, Win (Madix)

444A. Quantum Simulations of Molecules and Materials—Molecules and surfaces: quantum atomistic simulations of molecules and surfaces to predict atomic structure, properties, reaction mechanisms, and kinetics. Review of quantum mechanics. Electronic structure calculations: Hartree Fock, configuration interaction, many body perturbation theory, and density functional theory. Property calculations: energy, forces, structure, and electronic and vibrational spectra. Applications to semiconductor processing, surface science, biochemistry, catalysis, polymers, environmental chemistry, and combustion. Prerequisite: undergraduate level quantum mechanics.

3 units, Win (Musgrave)

450. Introduction to Biotechnology—(Same as Biochemistry 237, Civil and Environmental Engineering 237, Developmental Biology 237, Structural Biology 450.) Faculty from the departments of Biochemistry, Biological Sciences, Chemical Engineering, Civil and Environmental Engineering, Developmental Biology, Structural Biology, and invited industrial speakers review the interrelated elements of modern biotechnology. Topics: protein structure and dynamics, protein engineering, biocatalysis, gene expression, cellular metabolism and metabolic engineering, fermentation technology, and purification of biomolecules. Prerequisite: graduate student or upper-division undergraduate in the sciences or engineering.

3 units, Spr (Robertson, Swartz)

452. Protein Science and Engineering—(Same as Chemistry 232.) The physio-chemical interactions that govern the structure and function of proteins. Topics: protein function and structure, techniques for probing protein structure and function, mechanisms of protein function, design of proteins with novel properties. Examples from the literature on enzymes. Recommended: background in physical and organic chemistry.

3 units, Win (Khosla)

454. Metabolic Engineering Methods and Applications—The optimization of industrial organisms for maximal benefit. In the context of actual applications, metabolic pathways and how they are regulated, metabolic flux analysis, and traditional and rDNA methods for genetic engineering. Examples in the areas of: metabolite production, DNA protein production by bacteria and mammalian cells, petroleum biodesulfurization, bioremediation, and cell-free protein synthesis. Prerequisites: 250, 355 or equivalent

3 units, Spr (Swartz) alternate years, not given 2001-02

459. Frontiers in Interdisciplinary Biosciences—(Cross-listed in multiple departments in the schools of Humanities and Sciences, Engineering, and Medicine; students should enroll directly through their affiliated department, if at all possible.) Introduction to cutting-edge research involving interdisciplinary approaches to bioscience and biotechnology; for specialists and non-specialists. Associated with Stanford's Clark Center for Interdisciplinary Bioscience, and held in conjunction with a seminar series meeting twice monthly during 2000-01. Leading investigators from Stanford and throughout the world speak on their research; students also meet separately to present and discuss the ever-changing subject matter, related literature, and future directions. Prerequisite: keen interest in all of science, with particular interest in life itself. Recommended: basic knowledge of biology, chemistry, and physics.

2 units, Aut, Win, Spr (S. Block)

460. Polymer Physics—The application of statistical thermodynamics to elucidate structural properties of high molecular weight polymers. The conformation of single polymer chains in solution and the bulk with the analysis based on rotational isomeric state theory and the experimental verification coming from scattering measurements. Statistical thermodynamic analyses for the study of phase behavior in polymer solutions, blends blocks copolymers, and liquid crystals. Non-equilibrium features of glassy polymers, including theories of the glass transition and physical aging. The theories used to treat the kinetics of polymer crystallization, including the Avrami and Lauritzen-Hoffman approaches.

3 units, Spr (Frank) alternate years, not given 2001-02

462. Dynamics of Complex Liquids—Flow and orientation phenomena of polymeric and colloidal liquids; fundamental concepts of rheology; diffusion processes in complex liquids; molecular models of dilute and concentrated polymer solutions and melts (flexible and rigid systems); reptation and scaling theories of polymer liquids; introduction to liquid crystals, surfactant liquids, and suspensions. Prerequisites: 300, 310A.

3 units, Spr (Shaqfeh)

500-512. Special Topics in Chemical Engineering—Discussion of recent developments and current research in specialized fields. Units by arrangement. Prerequisite: consent of instructor.

Aut, Win, Spr

500A,B,C. Protein Biotechnology
(Swartz)

501A,B,C. Semiconductor Processing
(Bent)

502A,B,C. Computational Materials Science
(Musgrave)

503A,B,C. Biocatalysis
(Khosla)

504A,B,C. Bioengineering
(Robertson)

505A,B,C. Microrheology
(Fuller)

506A,B,C. Surface and Interface Science
(Madix)

507A,B,C. Polymer Physics and Molecular Assemblies
(Frank)

508A,B,C. Stability of Fluid Motions
(Homsy)

509A,B,C. Statistical Mechanics of Dispersed Systems
(Gast)

510A,B,C. Transport Mechanics
(Shaqfeh)

511A,B,C. NMR of Solids
(Klug)

512A,B,C. Functional Genomics
(Kao)

600. Graduate Research in Chemical Engineering—Lab and theoretical work for graduate students on chemical engineering problems leading to partial fulfillment of requirements for an advanced degree. Credit is given after the student has satisfied the specific report or dissertation requirement.

(Staff)

699. Colloquium—Students attend the colloquia of the Department of Chemical Engineering. Must be taken every quarter by candidates for advanced degrees in Chemical Engineering. (AU)

1 unit, Aut, Win, Spr (Staff)