Stevens Institute of Technology 2006-2007 Catalog

The Charles V. Schaefer, Jr. School of Engineering

Department of Chemical, Biomedical, and Materials Engineering

HENRY H. DU, DIRECTOR

FACULTY*

Professors Emeriti

Traugott E. Fischer, Sc.D. (1963), Federal Institute of Technology, Zurich
Milton Ohring, Ph.D. (1964), Columbia University
Harry Silla, Ph.D., (1970), Stevens Institute of Technology

Professors

Ronald S. Besser, Ph.D. (1990), Stanford University
George B. DeLancey, Ph.D. (1967), University of Pittsburgh
Henry H. Du, Ph.D. (1988), Pennsylvania State University
Bernard Gallois, George Meade Bond Professor, Ph.D. (1980), Carnegie Mellon University
Dilhan M. Kalyon (Director of Highly Filled Materials Institute), Ph.D. (1980), McGill University, Canada
Suphan Kovenklioglu, Ph.D. (1976), Stevens Institute of Technology
Adeniyi Lawal (Program Director), Ph.D. (1985), McGill University, Canada
Woo Young Lee (Director of New Jersey Center for Microcehmical Systems), Ph.D. (1990), Georgia Institute of Technology
Matthew R. Libera, Sc.D. (1987), Massachusetts Institute of Technology
Gerald M. Rothberg, Ph.D. (1959), Columbia University
Keith Sheppard (Associate Dean of the School of Engineering), Ph.D. (1980), Birmingham University, England

Assistant Professors

Hongjun Wang, Ph.D. (2003), Twente University, The Netherlands, Ph.D. (1988), Nankai University, China
Xiaojun Yu, Ph.D. (2002), Case Western Reserve University

Travel Directions

Campus Map

Distinguished Service Professor

Arthur B. Ritter (Program Director), Ph.D. (1970), University of Rochester

Senior Lecturer

Vikki Hazelwood, M.S. (1998), New Jersey Institute of Technology

Research Professor

Bahadir Karuv, Ph.D. (1994), Stevens Institute of Technology

*The list indicates the highest earned degree, year awarded, and institution where earned.

UNDERGRADUATE PROGRAMS

Chemical Engineering

A distinguishing feature of chemical engineers is that they create, design, and improve processes and products that are vital to our society. Today's high technology areas of biotechnology, electronic materials processing, ceramics, plastics, and other high-performance materials are generating opportunities for innovative solutions that may be provided from the unique background chemical engineers possess. Many activities in which a chemical engineer participates are ultimately directed toward improving existing chemical processes, or creating new ones.

Always considered to be one of the most diverse fields of engineering, chemical engineers are employed in research and development, design, manufacturing, and marketing activities. Industries served are diverse and include: energy, petrochemical, pharmaceutical, food, agricultural products, polymers and plastics, materials, semiconductor processing, waste treatment, environmental monitoring and improvement, and many others. There are career opportunities in traditional chemical engineering fields like energy and petrochemicals, but also in biochemical, pharmaceutical, biomedical, electrochemical, materials, and environmental engineering.

The chemical engineering program at Stevens is based on a solid foundation in the areas of chemical engineering science that are common to all of its branches. Courses in organic and physical chemistry, polymeric materials, biochemical engineerin,g and process control are offered in addition to chemical engineering thermodynamics, fluid mechanics, heat and mass transfer, separations, process analysis, reactor design, and process and product design. Thus, the chemical engineering graduate is equipped for the many challenges facing modern engineering professionals.

Chemical engineering courses include significant use of modern computational tools and computer simulation programs. Qualified undergraduates may also work with faculty on research projects. Many of our graduates pursue advanced study in chemical engineering, bioengineering or biomedical engineering, medicine, law, and many other fields.

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Mission and Objectives

The chemical engineering program educates technological leaders by preparing them for the conception, synthesis, design, testing, scale-up, operation, control and optimization of industrial chemical processes that impact our well being. Consistent with this mission statement the program's objectives are as follows:

The chemical engineers who complete the Stevens curriculum:

- Offer approaches to solutions of engineering problems that cut across traditional professional and scientific boundaries;
- Use modern tools of information technology on a wide range of problems;
- Contribute in a professional and ethical manner to chemical engineering projects in process or product development and design;
- Perform as effective team members, team leaders, and communicators;
- Participate in lifelong learning in the global economy; and
- Demonstrate awareness of health, safety, and environmental issues and the role of technology in society.

Our students are employed in commodity chemicals, pharmaceuticals, food and consumer products, fuels, and electronics industries, as well as in government laboratories. Also, our students attend graduate schools with international reputations in chemical engineering.

Course Sequence

A typical course sequence for chemical engineering is as follows:

Freshman Year				
Term I				
	Hrs. Per Wk.			
	Class	Lab	Study	Sem. Cred.

CH 115	General Chemistry I	3	0	6	3
CH 117	General Chemistry Lab I	0	3	0	1
MA 115	Calculus I	3	0	6	3
E 101	Eng. Experiences I #	1	0	0	0
E 121	Engineering Design I	0	3	2	2
E 120	Engineering Graphics	0	2	2	1
E 115	Intro. to Programming	1	1.5	3	2
HUM	Humanities	3	0	6	3
	# credit applied in E102				
TOTAL		**11**	**9.5**	**25**	**15**

Term II					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
CH 116	General Chemistry II (1)	3	0	6	3
CH 118	General Chemistry Lab II (1)	0	3	0	1
E 102	Engineering Experience II#	1	0	0	1
MA 116	Calculus II	3	0	6	3
PEP 111	Physics I	3	0	6	3
E 122	Engineering Design II	0	3	3	2
HUM	Humanities	3	0	6	3
	# credit for E101 & 102				
TOTAL		**13**	**6**	**27**	**16**

Sophomore Year					
Term III					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
MA 221	Differential Equations	4	0	8	4
PEP 112	Physics II	3	0	6	3
E 126	Mechanics of Solids	4	0	8	4

E 245	Circuits & Systems	2	3	7	3
E 231	Engineering Design III	0	3	2	2
HUM	Humanities	3	0	6	3
TOTAL		**16**	**6**	**37**	**19**

Term IV					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
MA 250	Multivariable Calculus **or** approved alternative**	3	0	6	3
E 232	Engineering Design IV	2	3	7	3
CHE 234	Bio./Chem. Eng. Thermodynamics**	3	0	6	3
PEP 201	Modern Physics for Eng. (1)	2	3	6	3
CHE 210	Process Analysis	3	0	3	3
HUM	Humanities	3	0	6	3
TOTAL		**16**	**6**	**34**	**18**

Junior Year					
Term V					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
CHE 342	Heat and Mass Transfer**	3	0	6	3
E 344	Materials Processing	3	0	6	3
E 321	Engineering Design V	0	3	2	2
CHE 332	Seperation Opers.	3	0	6	3
CHE 336	Fluid Mechanics	3	0	6	3
HUM	Humanities	3	0	6	3
TOTAL		**15**	**3**	**32**	**17**

Term VI					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
E 355	Engineering Economics	3	3	6	4
CHE 322	Engineering Design VI ‡	1	3	5	3
CHE 351	Reactor Design	3	0	6	3
E 243	Probability and Statistics	3	0	6	3
G.E.	General Elective (2)	3	0	6	3
TOTAL		**13**	**6**	**29**	**16**

Senior Year					
Term VII					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
CH 241	Organic Chemistry I	3	4	6	4
CHE 432	Chem. Eng. Lab	1	4	6	2
G.E.	General Elective (2)	3	0	6	3
CHE 423	Engineering Design VII‡	0	8	4	3
T.G.	Technogenesis Core**	3	0	6	3
T.E.	Chemistry Elective ‡	3	4	6	3
Total		**13**	**20**	**34**	**18**
Term VIII					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
CHE 345	Process Cont. and Simulation	3	0	6	3
T.E.	Chemistry Elective‡	3	4	6	4
G.E.	General Elective (2)	3	0	6	3
CHE 424	Chem. Eng. Design VIII ‡	0	8	4	3

HUM	Humanities	3	0	6	3
TOTAL		**12**	**12**	**28**	**16**

** Core option – specific course determined by engineering program
‡ Discipline-specific course
(1) Basic Science electives – note: engineering programs may have specific requirements
- one elective must have a laboratory component
- two electives from the same science field cannot be selected
(2) General Education Electives – chosen by the student
- can be used towards a minor or option
- can be applied to research or approved international studies

GRADUATION REQUIREMENTS

The following are requirements for graduation of all engineering students and **are not included for academic credit**. They will appear on the student record as pass/fail.

Physical Education

All engineering students must complete a minimum of three semester credits of Physical Education (P.E.). A large number of activities are offered in lifetime, team, and wellness areas. Students must complete at least one course in their first semester at Stevens; the other two can be completed at any time, although it is recommended that this be done within the first half of the students' program of study. Students can enroll in more than the minimum required P.E. for graduation and are encouraged to do so.

Participation in varsity sports can be used to satisfy the full P.E. requirement..

Participation in supervised, competitive club sports can be used to satisfy up to two credits of the P.E. requirement with approval from the P.E. Coordinator.

English Language Proficiency

All students must satisfy an English Language proficiency requirement.

PLEASE NOTE: *A comprehensive Communications Program will be implemented for the Class of 2009. This may influence how the English Language Proficiency requirement is met. Details will be added when available.*

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Minors

Students may qualify for a minor in biochemical, biomedical, or chemical engineering by taking the required courses indicated. Completion of a minor indicates proficiency beyond that provided by the Stevens curriculum in the basic material of the selected area. If you are enrolled in a minor program, you must meet the Institute requirements. In addition, the grade in any course credited for a minor must be "C" or better.

Requirements for a Minor in Biochemical Engineering for students enrolled in the Chemical Engineering curriculum

CH 241 Organic Chemistry I
CH 281 Biology and Biotechnology
CH 381 Cell Biology
CHE 480 Biochemical Engineering
or
EN 675 Biological Processes for Environmental Control

Requirements for a Minor in Biomedical Engineering for students enrolled in the Chemical Engineering curriculum

BME 306 Introduction to Biomedical Engineering
BME 506 Biomechanics
BME 505 Biomaterials
BME 504 Medical Instrumentation and Imaging
BME 482 Engineering Physiology*

*Prerequisites CH 281, CH 381

Requirements for a Minor in Chemical Engineering for students enrolled in the Engineering curriculum

CHE 210 Process Analysis
CHE 332 Separation Operations
CHE 342 Heat and Mass Transfer*
CHE 351 Reactor Design

* CHE 342 may be waived if appropriate substitutes have been taken in other programs.

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Biomedical Engineering

Mission and Objectives

The Stevens biomedical engineering program produces graduates who possess a broad foundation in engineering and liberal arts, combined with a depth of disciplinary knowledge. This knowledge is mandatory for success in a biomedical engineering career. Biomedical engineering is also an enabling step for a career in medicine, dentistry, business, or law.

The objectives of the biomedical engineering program are to prepare students to:

- Obtain employment and succeed in careers with companies and government organizations in the biomedical field, such as those in the areas of implant and device design and manufacturing, biomaterials, medical instrumentation, medical imaging, healthcare, oversight, and research;

- Utilize their broad-based education to define and solve complex problems, particularly those related to design, in the biomedical engineering field and effectively communicate the results;
- Understand and take responsibility for social, ethical, and economic factors related to biomedical engineering and its application;
- Function effectively on and provide leadership to multidisciplinary teams;
- Demonstrate a facility to seek and use knowledge as the foundation for lifelong learning; and
- Be prepared for successful advanced study in biomedical engineering or entry to graduate professional programs such as medicine, dentistry, business, or law.

Course Sequence

A typical Sequence for Biomedical Engineering is as follows:

Freshman Year					
Term I					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
CH 115	General Chemistry I	3	0	6	3
CH 117	General Chemistry Lab I	0	3	0	1
MA 115	Calculus I	3	0	6	3
E 101	Eng. Experiences I#	1	0	0	0
E 121	Engineering Design I	0	3	2	2
E 120	Engineering Graphics	0	2	2	1
E 115	Intro. to Programming	1	1.5	3	2
HUM	Humanities	3	0	6	3
	# credit applied in E102				
TOTAL		**11**	**9.5**	**25**	**15**
Term II					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
CH 116	General Chemistry II (1)	3	0	6	3

CH 118	General Chemistry Lab II (1)	0	3	0	1
E 102	Engineering Experience II#	1	0	0	1
MA 116	Calculus II	3	0	6	3
PEP 111	Physics I	3	0	6	3
E 122	Engineering Design II	0	3	3	2
HUM	Humanities	3	0	6	3
	# credit for E101 & 102				
TOTAL		**13**	**6**	**27**	**16**

Sophomore Year					
Term III					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
MA 221	Differential Equations	4	0	8	4
PEP 112	Physics II	3	0	6	3
E 126	Mechanics of Solids	4	0	8	4
E 245	Circuits & Systems	2	3	7	3
E 231	Engineering Design III	0	3	2	2
HUM	Humanities	3	0	6	3
TOTAL		**16**	**6**	**37**	**19**

Term IV					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
MA 250	Multivariable Calculus **or** approved alternative**	3	0	6	3
E 232	Engineering Design IV	2	3	7	3
CHE 234	Bio./Chem. Eng. Thermodynamics**	3	0	6	3
BME 306	Introduction to BME	3	0	6	3

CH 281	Biology and Biotechnology	3	0	6	3
CH 282	Biology Laboratory	0	3	3	1
HUM	Humanities	3	0	6	3
TOTAL		**17**	**6**	**40**	**19**

Junior Year					
Term V					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
CHE 342	Transport in Biosystems **	3	3	6	4
E 344	Materials Processing	3	0	6	3
E 321	Engineering Design V	0	3	2	2
CHE 241	Organic Chemsitry I	3	4	6	4
CHE 381	Cell Biology	3	3	6	4
HUM	Humanities	3	0	6	3
TOTAL		**15**	**13**	**32**	**20**

Term VI					
		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
E 355	Engineering Economics	3	3	6	4
BME 322	BME Design VI‡	1	3	5	3
BME 505	Biomaterials	3	0	6	3
BME 506	Biomechanics	3	0	6	3
CH 242	Organic Chemistry II (1)	3	4	6	4
(1) Required for BME majors in place of Basic Science Elective					
TOTAL		**13**	**10**	**29**	**17**

Senior Year
Term VII

		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
BME 482	Engineering Physiology	3	3	6	4
BME 504	Mechanical Instr. and Imaging	3	0	6	3
BME 423	BME Design VII‡	0	8	4	3
T.G.	Technogenesis Core**	3	0	6	3
E 243	Probabilty and statistics	3	0	6	3
Total		**12**	**14**	**28**	**16**

Term VIII

		Hrs. Per Wk.			
		Class	Lab	Study	Sem. Cred.
BME 445	Biosystems Simulation and Control	3	3	6	4
BME 453	Bioethics	3	0	6	3
G.E.	General Elective (2)	3	0	6	3
BME 424	BME Design VIII‡	0	8	4	3
HUM	Humanities	3	0	6	3
TOTAL		**12**	**11**	**28**	**16**

** Core option – specific course determined by engineering program
‡ Discipline-specific course(1) Basic Science electives – note: engineering programs may have specific requirements
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GRADUATE PROGRAMS

The department offers programs of study leading to the Master of Engineering and the Doctor of Philosophy degrees, as well as the professional degree of Chemical Engineer. Courses are offered in chemical, biochemical, biomedical, polymer, and materials engineering. The programs are designed to prepare you for a wide range of professional opportunities in manufacturing, design, research, or in development. Special emphasis is given to the relationship between basic science and its applications in modern technology. Chemical, biomedical and materials engineers create, design, and improve processes and products that are vital to our society. Our programs produce broad-based graduates who are prepared for careers in many fields and who have a solid foundation in research and development methodology. We strive to create a vibrant intellectual setting for our students and faculty anchored by pedagogical innovations and interdisciplinary research excellence. Active and well-equipped research laboratories in polymer processing, biopolymers, highly filled materials, microchemical systems, tissue engineering, high-performance coatings, photonic devices and systems, and nanotechnology are available for Ph.D. dissertations and master's theses.

Admission to the degree programs requires an undergraduate education in chemical, biomedical, or materials engineering. However, a conversion program enables qualified graduates of related disciplines (such as chemistry, mechanical engineering, physics, etc.) to enter the master's program through intensive no-credit courses designed to satisfy deficiencies in undergraduate preparation.

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Master's Programs

The Master of Engineering requires 30 graduate credits in an approved plan of study. Credits can be obtained by performing research in the form of a master's thesis. The Master of Engineering programs are developed with your objectives in mind. The curriculum must include the following courses:

Master of Engineering - Chemical

Chemical Engineering Concentration (10 Courses)

MA 530 Applied Mathematics
CHE 620 Chemical Engineering Thermodynamics
CHE 630 Theory of Transport Processes
CHE 650 Reactor Design

Plus six courses or thesis work.

Polymer Engineering Concentration (10 Courses)

MA 530 Applied Mathematics
CHE 620 Chemical Engineering Thermodynamics
CHE 630 Theory of Transport Processes
CHE 670 Polymer Properties and Structure
CHE 671 Polymer Rheology
CHE 672 Processing of Polymers for Biomedical Applications

Plus four courses or thesis work.

Chemical Engineer Program

The Degree of Chemical Engineer designates completion of a program of studies at the graduate level beyond the master's degree in scope, but with an overall objective. Students will be required to apply the subject matter acquired in formal graduate courses to a problem more consistent with one they are likely to encounter as a practicing engineer. Work on this problem in the form of an independent project will constitute a substantial part of the overall program of study. Specifically, it may be a design project, a process evaluation, or an engineering feasibility study involving economic, social, and managerial aspects.

Entrance requirements include a master's degree in chemical engineering (or equivalent) and one year of industrial experience. This is to be satisfied either before entering the program or during the course of the program.

The credit requirements are 30 credits beyond the master's degree in a program approved by your advisory committee (three faculty members, preferably including one member not in the department, assigned to you at the time of acceptance into the program). Of the 30 credits, a minimum of 8 and maximum of 15 credits will be given for the independent project.

In addition, on being accepted into the program, you will be expected to complete a set of placement examinations in chemical engineering for the purpose of constructing a suitable course of study. Your independent project must be approved by the advisory committee, defended publicly, bound according to specifications governing theses, and placed in the library. A time limit of six years is set for completion of the program.

Master of Engineering - Biomedical

Success in the field of medical technologies requires a highly interdisciplinary approach. A symbiotic relationship between these four discrete areas must be struck: clinical, industry, patient, and device. Failure to satisfy the requirements and expectations in any one area could prohibit the acceptance of a product or therapy. Certainly, the best and most elegant solutions will satisfy the requirements and expectations of each of the areas.

The core of the Stevens Biomedical Engineering program is distinguished by its consideration of these areas as an integrated system, each area representing a group of critical components required in order for the system to operate. Many other programs fail to consider all four of these components or fail to integrate them comprehensively.

The Stevens BME M.E. program allows for study in one of three avenues: advanced interdisciplinary biomedical engineering research, advanced training in biomedical engineering for engineers with an undergraduate degree in another discipline, or as a minor concentration for graduate engineers in other disciplines. In addition, the research avenue can lead directly into a Ph.D. program.

Common Requirements for Students with BME/Non-BME Background:

1. Required Courses (6 credits):

    BME 600 Strategies and Principles in Design (3)
    BME 601 Advanced Biomedical Engineering Lab (3)

2. Research or Special project + Elective (9 credits)

    a. BME 900 Thesis (9) **or**
    b. BME 950 Design Project (6) + BME Elective (3)

3. Additional requirements for students with a non-BME Engineering degree:

Prerequisite or Ramp-up courses

Introductory Biology* (3 non-graduate credits)
BME 453 Bioethics (3 non-graduate credits)
BME 503 Physiology (3 non-graduate credits)

May be taken at any school with approval

4. Guided selection of technical electives (15 credits)

Example Study Plans for BME M.E. Students

A. Students entering with an undergraduate degree in Biomedical Engineerig.

Example of an M.E. (Biomedical) program with a concentration in Regenerative Engineering.

Semester I

BME 600 Strategies and Principles in Biomedical Design
BME 602 Tissue Engineering
BME 603 Topics in Biological Transport

Semester II Spring Semester

BME 650 Advanced Biomaterials
BME 655 Principles of Multi-Scale Bio-Systems Development and Integration
BME 601 Advanced Biomedical Engineering Lab

Semester III

BME 900 Thesis (9)
BME Elective (3)

B. Students entering with an undergraduate degree in Chemical Engineering (with a 1 semester Biology Course).

Example of an M.E. (Biomedical) program with a concentration in Soft Materials:

Semester I

BME 600 Strategies and Principles in Biomedical Design
BME 503 Physiology (note: no graduate credit)
BME 603 Topics in Transport Phenomena

Semester II

BME 453 Bioethics (note: no graduate credit)
BME 601 Advanced Biomedical Engineering Lab
BME Elective (6)

CHE 672 Polymer Processing for Biomedical Applications

Semester III

BME 950 Design Project (6)
CHE 671 Rheology of Soft Materials
BME 655 Principles of Multi-Scale Biosystems Development and Integration

Master of Engineering - Materials

Materials Engineering (10 Courses)

MT 601 Structure and Diffraction
MT 602 Principles of Inorganic Materials Synthesis
MT 603 Thermodynamics and Reaction Kinetics of Solids

Plus 7 courses and/or thesis work

The Materials Engineering program offers, jointly with Electrical and Computer Engineering (EE) and Physics and Engineering Physics (PEP), a unique interdisciplinary concentration in Microelectronics and Photonics Science and Technology. Intended to meet the needs of students and of industry in the areas of design, fabrication, integration, and applications of microelectronic and photonic devices for communications and information systems, the program covers fundamentals, as well as state-of-the-art industrial practices. Designed for maximum flexibility, the program accommodates the background and interests of students with either a master's degree or graduate certificate.

Microelectronics and Photonics Science and Technology - Interdisciplinary

Core Courses

MT 507 Introduction to Microelectronics and Photonics

Three additional courses from the Materials core (listed above).

Six electives are required from the courses offered below by Materials Engineering, Physics, and Engineering Physics and Electrical Engineering. Three of these courses must be from Materials Engineering and at least one must be from each of the other two departments. Ten courses are required for the degree.

Required Concentration Electives

PEP 503 Introduction to Solid State Physics
PEP 515 Photonics I

PEP 516 Photonics II
PEP 561 Solid State Electronics I
MT 562 Solid State Electronics II
MT 595 Reliability and Failure of Solid State Devices
MT 596 Microfabrication Techniques
EE 585 Physical Design of Wireless Systems
EE 626 Optical Communication Systems
CPE 690 Introduction to VLSI Design

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Doctoral Program

Admission to the Chemical or Materials Engineering doctoral program is based on evidence that a student will prove capable of scholarly specialization in a broad intellectual foundation of a related discipline. The master's degree is strongly recommended for students entering the doctoral program. Applicants without the master's degree will normally be enrolled in the master's program.

Ninety credits of graduate work in an approved program of study are required beyond the bachelor's degree; this may include up to 30 credits obtained in a master's degree program, if the area of the master's degree is relevant to the doctoral program. A doctoral dissertation for a minimum of 30 credits and based on the results of your original research, carried out under the guidance of a faculty member and defended in a public examination, is a major component of the doctoral program. The Ph.D. qualifying exam consists of an oral exam only. Students are strongly encouraged to take the qualifying exam within two semesters of enrollment in the graduate program. A minimum of 3.3 GPA must be satisfied in order to take the exam. A time limit of six years is set for completion of the doctoral program.

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Doctoral Program - Interdisciplinary

An interdisciplinary Ph.D. program is jointly offered with the Department of Physics and Engineering Physics and the the Department of Chemistry and Chemical Biology. This program aims to address the increasingly cross-cutting nature of doctoral research in these disciplines. The interdisciplinary Ph.D. program aims to take advantage of the complementary educational offerings and research opportunities in these areas. Any student who wishes to enter this interdisciplinary program needs to obtain the consent of the three departments and the subsequent approval of the Dean of Academic Administration. The student will follow a study plan designed by his/her faculty advisor(s). The student will be granted official candidacy in the program upon successful completion of a qualifying exam that will be administered according to the applicable guidelines of the Office of Graduate Admissions. All policies of the Office of Graduate Admissions that govern the credit and thesis requirements apply to students enrolled in this interdisciplinary program. Interested students should follow the normal graduate application procedures through the Dean of Academic Administration.

Doctoral Program – Nanotechnology Concentration

Chemical and Materials Engineering doctoral programs are an integral part of the Institute-wide Nanotechnology Graduate Program. Ph.D. degree options in these disciplines with a Nanotechnology concentration are available to students who satisfy the conditions and requirements outlined in a separate section of this catalog.

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Research

A thesis for the master's or doctoral program can be completed by participating in one of the following research programs of the department.

- Biologically Active Material - Professor Libera
- Biochemical Engineering - Professor DeLancey
- Biomaterials Design, Cellular, and Tissue Engineering, and Cell Signaling – Professor Wang
- Cellular Processes and their Dependence on Organization and Composition of Extracellular Matrix Environment in Mammalian Tissues – Professor Xu (CCB)
- Crystallization - Professors Kovenklioglu and Kalyon
- Design of Spinal and Orthopaedic Implants – Professors Haher and Valdevit
- Electron Microscopy and Polymer Interfaces - Professor Libera
- Exercise Physiology and Concussion Management – Professor Hazelwood
- Mathematical Modeling of Physiological Systems, Bioreactor Design, and Scaleup – Professor Ritter
- Mathematical Modeling and Simulation of Transport Processes – Professor Lawal
- Medical Imaging – Professor Man (ECE)
- Microchemical Systems - Professors Lee, Lawal, Besser, and Kovenklioglu
- Polymer Characterization and Processing - Professor Kalyon
- Rheology Modeling Processability and Microstructure of Filled Materials - Professor Kalyon
- Surface Modification at Multiple Length Scales, Photonic Sensing, High-Temperature Oxidation - Professor Du
- Surface Science and Engineering - Professor Rothberg

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Graduate Certificate Programs

In addition to the degree programs, the department also offers graduate certificate programs. In most cases, the courses may be used toward the master's degree. Each graduate certificate program is a self-contained and highly focused collection of courses carrying nine or more graduate credits. The selection of courses is adapted to the professional interests of the student.

The Graduate Certificate in Pharmaceutical Manufacturing Practices is an interdisciplinary School of Engineering certificate developed by the Department of Mechanical Engineering and the Department of Chemical, Biomedical and Materials Engineering. This certificate is intended to provide professionals with skills required to work in the pharmaceutical industry. The focus is on engineering aspects of manufacturing and the design of facilities for pharmaceutical manufacturing, within the framework of the regulatory requirements in the pharmaceutical industry.

The certificate is designed for technologists in primary manufacturers, including pharmaceutical, biotechnology, medical device, diagnostic, and cosmetic companies, as well as in related companies and organizations, including architect/engineer/construction firms, equipment manufacturers and suppliers, government agencies, and universities.

Biomedical Engineering

BME 506 Biomechanics
BME 505 Biomaterials
BME 504 Medical Instrumentation and Imaging
BME 503 Physiological Systems

Pharmaceutical Manufacturing Practices

PME 530 Introduction to Pharmaceutical Manufacturing
PME 535 Good Manufacturing Practice in Pharmaceutical Facilities Design
PME 540 Validation and Regulatory Affairs in Pharmaceutical Manufacturing

and *one* of the following electives:

PME 628 Pharmaceutical Finishing and Packaging Systems
PME 538 Chemical Technology Processes in API Manufacturing
PME 649 Design of Water, Steam, and CIP Utility Systems for Pharmaceutical Manufacturing (M.E. Graduate Course)
PME 531 Process Safety Management (CHE Graduate Course)

(Full course descriptions can be found in the Interdisciplinary Programs section.)

Photonics

EE/MT/PEP 507 Introduction to Microelectronics and

Photonics
EE/MT/PEP 515 Photonics I
EE/MT/PEP 516 Photonics II
EE/MT/PEP 626 Optical Communication Systems

Microelectronics
EE/MT/PEP 507 Introduction to Microelectronics and Photonics
EE/MT/PEP 561 Solid State Electronics I
EE/MT/PEP 562 Solid State Electronics II
CpE/MT/PEP 690 Introduction to VLSI Design

Microdevices and Microsystems
EE/MT/PEP 507 Introduction to Microelectronics and Photonics
EE/MT/PEP 595 Reliability and Failure of Solid State Devices
EE/MT/PEP 596 Micro-Fabrication Techniques
EE/MT/PEP 685 Physical Design of Wireless Systems

Any *one* elective in the three certificates above may be replaced with another within the Microelectronics and Photonics (MP) curriculum upon approval from the MP Program Director.

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UNDERGRADUATE COURSES

Chemical Engineering

CHE 210 Process Analysis
(3-0-3)
Introduction to the most important processes employed by the chemical industries, such as plastics, pharmaceutical, chemical, petrochemical, and biochemical. Major emphasis is on formulating and solving material and energy balances for simple and complex systems. Equilibrium concepts for chemical process systems are developed and applied. Computer courseware utilized where appropriate. Prerequisites: CH 116, MA 221, and E 115.

CHE 234 Bio/Chemical Engineering Thermodynamics
(3-3-4)
Thermodynamic laws and functions with particular emphasis on systems of variable composition and chemically reacting systems. Chemical potential, fugacity and activity, excess function properties, standard states, phase and reaction equilibria, reaction coordinate, and chemical-to-electrical energy conversion. Prerequisites: CH 116, MA 221, and E 115. Cross-listed with BME 234.

CHE 322 Engineering Design VI
(1-4-3)
The objectives of this course are to learn modern systematic design strategies for steady state chemical processing systems and at the same time to gain a functional facility with a process simulator (Aspen) for design, analysis, and economic evaluation. A process is

constructed stepwise, with continuing discussion of heuristics, recycle, purge streams, and other process conditions. Aspen is used for design and analysis of the process units. From the viewpoint of the process simulations, the course is divided into four categories: component, property, and data management; unit operations; system simulation; and process economic evaluation. The equations used by the simulator are discussed, as well as convergence methods, loops and tear streams, and scrutiny of default settings in the simulator. The factored cost method and profitability measures are reviewed and compared to simulator results. Work on a capstone design project is begun in the last section of the course. Prerequisite: CHE 332. Corequisite: CHE 351.

CHE 332 Separation Operations
(3-0-3)
The design of industrial separation equipment using both analytical and graphical methods is studied. Equilibrium-based design techniques for single and multiple stages in distillation, absorption/stripping, and liquid-liquid extraction are employed. An introduction to gas-solid and solid-liquid systems is presented, as well. Mass transfer considerations are included in efficiency calculations and design procedures for packed absorption towers, membrane separations, and absorption. Ion exchange and chromatography are discussed. The role of solution thermodynamics and the methods of estimating or calculating thermodynamic properties are also studied. Degrees of freedom analyses are threaded throughout the course, as well as the appropriate use of software. Iterative rigorous solutions are discussed as bases for Aspen simulation models used in Design VI. Prerequisite: CHE 210.

CHE 336 Fluid Mechanics
(3-0-3)
An exploration of the important concepts of fluids (gases and liquids) for all sub-disciplines within chemical engineering. Underlying principles and practical applications. Application of appropriate computer methods to solving fluids problems. Topics include hydrostatics, mass, and energy balances in fluid flow, laminar and turbulent flows, fluid friction, and basic approaches to designing flow systems.

CHE 342 Heat and Mass Transfer
(3-0-3)
Heat conduction, convection, and radiation. General differential equations for energy transfer. Conductive and convective heat transfer, equipment, and radiation heat transfer. Molecular, convective, and interface mass transfer. The differential equation for mass transfer. Steady state molecular diffusion and film theory. Convective mass transfer correlations. Mass transfer equipment. Prerequisites: MA 227, E 234.

CHE 345 Process Control, Modeling, and Simulation

(3-0-3)
Development of deterministic and non-deterministic models for physical systems, engineering applications, and simulation tools for case studies and projects. Prerequisite: CHE 332. Corequisite: CHE 351.

CHE 351 Reactor Design
(3-0-3)
Chemical equilibria and kinetics of single and multiple reactions are analyzed in isothermal and non-isothermal batch systems. Conversion, yield, selectivity, temperature, and concentration history are studied in ideal plug flow, laminar flow, continuous stirred tank, and heterogeneous reactors. The bases of reactor selection are developed. Consideration is given to stability and optimization concepts, and the interaction of the reactor with the overall processing system. Prerequisites: CHE 210, CHE 342, CHE 336.

CHE 423-424 Senior Design
(0-8-3) (0-8-3)
Senior Design provides, over the course of two semesters, a collaborative design experience with a problem of industrial or societal significance. Projects can originate with an industrial sponsor, from an engineering project on campus, or from other industrial or academic sources. In all cases, a project is a capstone experience that draws extensively from the student's engineering and scientific background and requires independent judgments and actions. Advice from the faculty and industrial sponsors is made readily available. The projects generally involve a number of unit operations, a detailed economic analysis, simulation, use of industrial economic and process software packages, and experimentation and/or prototype construction. The economic thread initiated in Design VI is continued in the first semester of Senior Design by close interaction on a project basis with E 421. Leadership and entrepreneurship are nourished throughout all phases of the project. The project goals are met stepwise, with each milestone forming a part of a final report with a common structure. Prerequisites: CHE 322, CHE 351, and CHE 345.

CHE 432 Chemical Engineering Systems Laboratory
(1-4-2)
A laboratory course designed to illustrate and apply chemical engineering fundamentals. The course covers a range of experiments involving mass, momentum and energy, transport processes, and basic unit operations such as distillation, stripping, and multi-phase catalytic reactions. Prerequisites: CHE 332, CHE 351.

CHE 480 Biochemical Engineering
(3-0-3)
Integration of the principles of biochemistry and microbiology into chemical engineering processes, microbial kinetic models, transport in bioprocess systems, single and mixed culture fermentation

technology, enzyme synthesis, purification and kinetics, bioreactor analysis, design and control, product recovery, and downstream processing. Prerequisite: CHE 351.

CHE 498-499 Research in Chemical Engineering I-II
(0-6-2) (0-6-2)
Individual investigation of a substantive character undertaken at an undergraduate level under the guidance of a member of the departmental faculty. A written report is required. Hours to be arranged with the faculty advisor. Prior approval required. This course cannot be used for degree requirements.

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Biomedical Engineering

BME 234 Biology/Chemical Engineering Thermodynamics
(3-3-4)
Thermodynamic laws and functions with particular emphasis on systems of variable composition and chemically reacting systems. Chemical potential, fugacity, and activity, excess function properties, standard states, phase and reaction equilibria, reaction coordinate, and chemical-to-electrical energy conversion. Prerequisites: CH 116, MA 221, and E 115. Cross-listed with CHE 234.

BME 281 Introductory Quantitative Biology
(3-0-3)
Topics in general biology are discussed from a quantitative point of view to develop an appreciation for biology, mathematics, and the connections between them. Living systems are viewed through an engineering perspective as open systems with mass, energy, and flow entering and leaving. The interaction of the component parts of living systems at the molecular, cellular, tissue, organism, and ecosystem levels are explored through descriptive and quantitative models. Modules will include cellular processes and human physiology. The diversity and evolution of living organisms is explored. Interactions among organisms and with their environment, including toxic substances, are examined in the module on ecology and ecotoxicology. No previous exposure to biology is assumed. A basic understanding of the derivative is assumed, such as may be obtained from a concurrent first semester course in differential calculus. Other relevant mathematical principles are introduced at the beginning of each module.

BME 306 Bioengineering
(3-0-3)
Overview of the biomedical engineering field with applications relevant to the healthcare industry, such as medical instrumentation and devices. Introduction to the nervous system, propagation of the action potential,

muscle contraction, and introduction to the cardiovascular system. Discussion of ethical issues in biomedicine.

BME 322 Engineering Design VI
(1-3-2)
Introduction to the principles of wireless transmission and the design of biomedical devices and instrumentation with wireless capabilities (e.g. pacemakers, defibrilators, and EKG). Electrical safety (isolation and shielding) and equipment validation standards for FDA compliance are introduced. Use of LabView to provide virtual bioinstrumentation. The course culminates in group projects to design a biomedical device that runs on wireless technology. Prerequisite: BME 306.

BME 342 Transport in Biological Systems
(3-3-4)
A study of momentum, mass, and heat transport in living systems. Rheology of blood. Basic hemodynamics. Use of the equations of continuity and motion to set up complex flow problems. Flow within distensible tubes. Shear stress and endothelial cell function. Mass transfer and metabolism in organs and tissues. Microscopic and macroscopic mass balances. Diffusion. Blood-tissue transport of solutes in the microcirculation. Compartmental models for pharmacokinetic analyses. Analysis of blood oxygenators, hemodialysis, and tissue growth in porous support materials. Artificial organs. Energy balances and the use of heat to treat tumor growth (radio frequency ablation and cryogenic ablation). Laboratory exercises accompany major topics discussed in class and are conducted at the same time. Prerequisites: BME 306 and MA 221.

BME 423-424 Senior Design
(0-8-3) (0-8-3)
Senior design courses. Senior design provides, over the course of two semesters, a collaborative design experience with a significant biomedical problem related to human health. The project will often originate with an industrial sponsor or a medical practitioner at a nearby medical facility and will contain a clear implementation objective (i.e. for a medical device). It is a capstone experience that draws extensively on the student's engineering and scientific background and requires independent judgments and actions. The project generally involves a determination of the medical need, a detailed economic analysis of the market potential, physiological considerations, biocompatibility issues, ease of patient use, an engineering analysis of the design, manufacturing considerations, and experimentation and/or prototype construction of the device. The faculty advisor, industrial sponsor, or biomedical practitioner works closely with the group to insure that the project meets its goals in a timely way. Leadership and entrepreneurship are nourished throughout all phases of the project. The project goals

are met in a stepwise fashion, with each milestone forming a part of a final report with a common structure. Oral and written progress reports are presented to a panel of faculty at specified intervals and at the end of each semester. Prerequisites. BME 306, BME 342, and BME 322. Corequisites: BME 482, E243.

BME 445 Biosystems Simulation and Control
(3-3-4)
Time and frequency domain analysis of linear control systems. Proportional, derivative, and integral control actions. Stability. Applications of control theory to physiological control systems: biosensors, information processors, and bioactuators. Mathematical modeling and analysis of heart and blood pressure regulation, body temperature regulation, regulation of intracellular ionic concentrations, eye movement, and pupil dilation controls. Use of Matlab and Simulink to model blood pressure regulation, autoregulation of blood flow, force development by muscle contraction, and integrated response of cardiac output, blood pressure, and respiration to exercise.

BME 453 Bioethics
(3-0-3)
This course focuses on professional ethical conduct in the biomedical field. It will enable students to understand the ethical challenges they may encounter as biomedical engineers, allow them to practice biomedical engineering in an ethical manner, and conduct themselves ethically as contributing members of society. Case discussions and presentations by practitioners in the field illustrate ethical norms and dilemmas.

BME 482 Engineering Physiology
(3-3-4)
Introduction to mammalian physiology from an engineering point of view. The quantitative aspects of normal cellular and organ functions and the regulatory processes required to maintain organ viability and homeostasis will be discussed. Topics include: nNeuro, muscle, cardiovascular, respiratory, renal, and endocrine physiology.

BME 498-499 Research in Biomedical Engineering I-II
(0-6-2) (0-6-2)
Individual investigation of a substantive character undertaken at an undergraduate level under the guidance of a member of the departmental faculty. A written report is required. Hours to be arranged with the faculty advisor. Prior approval required. These courses can be used as general electives for degree requirements.

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GRADUATE COURSES

All Graduate courses are 3 credits except where noted.

Chemical Engineering Courses

CHE 501 Mass and Energy Balances, Stagewise Operations
This course serves as an introduction to chemical engineering for those with no previous training in the field. Among the topics covered are mass and energy balances and equilibrium stagewise operations. No credit for graduate CHE majors.

CHE 502 Transport Phenomena
This introductory course in chemical engineering covers mass, heat, and momentum transfer. A background in ordinary and partial differential equations is required. CHE 501 is not a prerequisite. No credit for graduate CHE majors.

CHE 531 Process Safety Management
This course addresses management and engineering design concepts required for process safety in chemical and biotechnology systems, with pharmaceutical manufacturing applications. The basis for the course is a Process Safety Management (PSM) model from OSHA and the Center for Chemical Process Safety of AICHE . Content focuses on sound engineering principles and practices as they apply to industrial situations, project design, risk mitigation, process, and equipment integrity, and engineering codes and standards. Includes calculation of risk assessment scores and cost justification factors; HASOPs studies using P&IDs; sizing safety valves, rupture discs, explosion venting, and emergency scrubbers; MSDS applied to dispersion modeling; overall control, reduction, and prevention of hazardous materials incidents; and case studies.

CHE 539 Bioprocess Technology in API Manufacturing
This course provides a broad overview of topics related to the design and operations of modern biopharmaceutical facilities. It covers process, utilities, and facility design issues, and encompasses all major manufacturing areas, such as fermentation, harvest, primary and final purification, media and buffer preparation, equipment cleaning and sterilization, and critical process utilities. Unit operations include cell culture, centrifugation, conventional and tangential flow filtration, chromatography, solution preparation, and bulk filling. Application of current Good Manufacturing Practices and Bioprocessing Equipment Standards (BPE-2002) will be discussed. Cross-listed with PME 539 and ME 539.

CHE 564 Microprocessors in Process Control
Designed to provide the process engineers with the background necessary to understand and work with microprocessor-based systems. Topics include: introduction and overview of microprocessor-based technology in chemical engineering; analog and digital

signal conditioning, data transmission, and serial interfacing using RS-232C and GPIB IEEE-488 standards; analog-to-digital conversion and sampling; digital-to-analog conversion; digital I/O, switches/relays, and power supplies; microprocessor-based sensors, transducers, and actuators; programmable logic controllers and batch process control; and software packages for data-acquisition and control. Prerequisites: Undergraduate course in circuits and process control.

CHE 610 Process Synthesis, Analysis, and Design
Development and evaluation of processing schemes; analysis of process circuits; establishing design criteria; process design; evaluation and selection of process equipment; economic analysis and evaluation; and applications to chemical, biochemical, waste treatment, energy, and other processes of current interest.

CHE 611 Design of Separation Processes
Selection, design, and scaling of separation processes using principles of momentum, energy and mass transfer, and applications to novel, as well as to conventional, separation techniques.

CHE 612 Stagewise Operations
The ultimate goal of this course is to prepare students to undertake the analysis of the most difficult problems in equilibrium stage operations. The problems typically involve one or more columns with components exhibiting highly non-ideal behavior. This class of problems includes azeotropic distillation, extractive distillation, columns with more than one liquid phase, and a variety of other anomalies. Lack of complete equilibrium data is not uncommon. Extensive use is made of commercial software in the solution of problems. The course concludes with the assignment of an industrial problem, a substantial project, which requires that the students exercise virtually all techniques studied.

CHE 620 Chemical Engineering Thermodynamics
This course supplements the classical undergraduate thermodynamics course by focusing on physical and thermodynamic properties and phase equilibria. A variety of equations of state, and their applicability, are introduced, as are all of the important liquid activity coefficient equations. Customization of both vapor and liquid equations is introduced by appropriate methods of applied mathematics. Vapor-liquid, liquid-liquid, vapor-liquid-liquid, and solid-liquid equilibria are considered with rigor. Industrial applications are employed. A variety of methods for estimating physical and thermodynamic properties are introduced. Students are encouraged to use commercial software in applications. The course concludes with an introduction to statistical thermodynamics.

CHE 630 Theory of Transport Processes
Generalized approach to differential and macroscopic

balances: constitutive material equations; momentum and energy transport in laminar and turbulent flow; interphase and intraphase transport; and dimensionless correlations.

CHE 639 Modeling and Simulation of Pharmaceutical Manufacturing Systems
This course will review identification of pharmaceutical processes and systems, model formulation, algorithm development, and solution techniques of relevance to pharmaceutical manufacturing. Development of concepts and analysis skills necessary for modeling and simulation of pharmaceutical manufacturing processes and systems are emphasized. Overview of modeling techniques, process model development, product and assembly models, optimization techniques, and methods used in decision analysis, including multi-attribute utility models, decision trees, and discrete event simulation is presented. Prerequisite: undergraduate degree in engineering or its equivalent. Cross-listed with: ME 639 and PME 639.

CHE 641 New Separation Processes
The course begins with a review of traditional separation processes such as distillation, evaporation, extraction, crystallization, and absorption. New topics in separation which are covered include pressure swing adsorption, molecular sieves, ion exchange, reverse osmosis, microfiltration, nanofiltration, ultrafiltration, diafiltration, gas permeation, pervaporation, and supercritical fluid extraction and liquid chromatography. Industrial applications, design considerations, and engineering analysis of these separation topics are covered.

CHE 650 Reactor Design
Analysis of batch and continuous chemical reactions for homogeneous, heterogeneous, catalytic, and noncatalytic reactions; influence of temperature, pressure, reactor size and type, mass and heat transport on yield, and product distribution; and design criteria based on optimal operating conditions and reactor stability will be developed.

CHE 660 Advanced Process Control
Mathematical modeling and identification of chemical processes. State-space process representation and analysis: stability, observability, controllability, and reachability. Analysis and design of advanced control systems: internal model control, dynamic matrix control, and model predictive control. Synthesis of multivariable control systems: interaction analysis, singular value decomposition, and decoupler design. Continuous and sampled-data systems and on-line process identification. State and parameter estimation techniques: Luenberger observer and Kalman filter. Knowledge of Laplace transforms, material and energy balances, computer programming, and matrix algebra is required. Prerequisite: an undergraduate course in process control.

CHE 661 Design of Control Systems
This course focuses on the application of advanced process control techniques in pharmaceutical and petrochemical industries. Among the topics considered are bioreactor and polymerization reactor modeling, biosensors, state and parameter estimation techniques, optimization of reactor productivity for batch, fed-batch and continuous operations, and expert systems approaches to monitoring and control. An overview of a complete automation project - from design to startup - of a pharmaceutical plant will be discussed. Included: process control issues and coordination of interdisciplinary requirements and regulations. Guest speakers from local industry will present current technological trends. A background in differential equations, biochemical engineering, and basic process control is required. Cross-listed with ME 623.

CHE 662 Chemical Process Simulation
The course comprises a series of workshops, employing an industrial process simulator, Aspen Plus, which explore the primary components required to simulate a chemical process. Most workshops have embedded irregularities designed to heighten the student-awareness of the types of errors that could arise when using simulation software. The workshops include facilities to exercise and customize a wide variety of physical and thermodynamic properties as the students develop process models. Heavy concentration is on the equations describing the models used. As the experience level of the students rises, workshops designed to introduce complicated industrial flowsheets are employed.

CHE 670 Polymer Properties and Structure
Stress-strain relationships, theory of linear viscoelasticity and relaxation spectra, temperature dependence of viscoelastic behavior, dielectric properties, dynamic mechanical and electrical testing, molecular theories of flexible chains, statistical mechanics and thermodynamics of rubber-like undiluted systems, and morphology of high polymers. Cross-listed with MT 670.

CHE 671 Polymer Rheology
Molecular and continuum mechanical constitutive equations for viscoelastic fluids; analysis of viscometric experiments to evaluate the viscosity and normal stress functions; dependence of these functions on the macromolecular structure of polymer melts; solution of isothermal and nonisothermal flow problems with non-Newtonian fluids which are encountered in polymer processing; and development of design equations for extruder dies and molds. Prerequisite: CHE 630.

CHE 672 Processing of Polymers for Biomedical Applications
Descriptions of various polymer processing operations and processing requirements of biomedical products,

principles of processing of polymers covering melting, pressurization, mixing, devolatilization, shaping using extrusion, spinning, blowing, coating, calendering and molding technologies, surface treatment and sterilization, and applications in the areas of prostheses and artificial organs and packaging of various biomedical devices. Prerequisite: CHE 630.

CHE 675 Polymer Blends and Composites
Recent advances in polymer blend and composite formation; the role of melt rheology in component selection and the resulting morphology; melt mixing processes and equipment; models for predicting processing and performance characteristics; morphology generation and control in manufacturing processes; and sample calculations and case histories for polyblends used in film blowing, blow molding, and injection molding.

CHE 676 Polymer Mold and Die Design
Principal manufacturing methods utilizing molds and dies; mold and die design characteristics dictated by functional requirements; interaction between molds/dies and processing machinery; mathematical models of forming processes, including flow through dies and into molds, solidification, heat transfer, and reaction (in reactive processing); end-product properties (morphology, bulk properties, tolerances, and appearance) and operating conditions in alternative manufacturing methods; materials and manufacturing methods for molds and dies; and case studies.

CHE 677 Polymer Product Design
Design of polymeric products; design criteria based upon product functions and geometry; material selection by property assessment; selection of molds, dies, and special manufacturing devices (e.g., mold inserts); selection of appropriate forming process (injection, rotational or blow-molding, extrusion, etc.); and determination of optimum operating conditions (such as temperature, pressure, cycle, or residence time). Case histories of failure.

CHE 678 Experimental Methods in Polymer Melt Rheology
Discussion of models for flow and deformation in polymers, and a treatment of measurable rheological properties. Analysis of thermoplastic and thermosetting resins for processability. Use of experimental data to determine parameters of the constitutive equations. Laboratory includes use of state-of-the-art equipment in elongational, rotational, and capillary viscometry.

CHE 681 Biochemical Engineering
Integration of the principles of biochemistry and microbiology into chemical engineering processes; microbial kinetic models; transport in bioprocess systems; single and mixed culture fermentation technology; enzyme synthesis, purification, and kinetics; bioreactors analysis, design, and control; and

product recovery and downstream processing.

CHE 682 Colloids and Interfacial Phenomena
A survey course covering the chemical, biological, and material science aspects of interfacial phenomena. Applications to adhesion, biomembranes, colloidal stability, detergency, lubrication, coatings, fibers, and powders where surface properties play an important role. Prerequisites: CH 421, CH 321, and E 321 or equivalent.

CHE 695 Bio/Nano Photonics
This course deals with the principles of light interactions with biological and biomedical-relevant systems. The enabling aspects of nanotechnology for advanced biosensing, medical diagnosis, and therapeutically treatment will be discussed. Prerequisite: NANO 600. Cross-listed with BME 695, MT 695, and NANO 695.

CHE 700 Seminar in Chemical Engineering
Lectures by department faculty, guest speakers, and doctoral students on recent research. Enrollment during the entire period of study is required of all full-time students. No credit. Must be taken every semester. Cross-listed with BME/MT 700.

CHE 701-702 Selected Topics in Chemical Engineering III-IV
Selected topics of current interest in the field of chemical engineering will be treated from an advanced point of view.

CHE 703 Numerical Methods in Chemical Engineering
The course is designed to enable students to attack a variety of chemical engineering problems which lend themselves to solution by numerical methods as opposed to classical mathematics. Problems that do not fit the mold "using existing software" are illustrated. The students are encouraged to create their own software to solve problems. For this purpose, students are given an introduction to the Visual Basic programming language. Students are also encouraged to use more advanced methods in Excel. Examples and homework assignments are drawn from industrial experience when possible.

CHE 770-771 Selected Topics in Polymer Science and Engineering III-IV
A critical review of current theories and experimental aspects of polymer science and engineering. (Three to six credits.)

CHE 800 Special Problems in Chemical Engineering*
One to six credits. Limit of six credits for the degree of Master of Engineering (Chemical).

CHE 801 Special Problems in Chemical Engineering*
One to six credits. Limit of six credits for the degree of Doctor of Philosophy.

CHE 802 Special Problems in Chemical Engineering
For the degree of Chemical Engineer. (One to six credits.)

CHE 900 Thesis in Chemical Engineering*
For the degree of Master of Engineering (Chemical). Five to ten credits with departmental approval.

CHE 950 Chemical Engineer Design Project*
Design project for the degree of Chemical Engineer. Hours and credits to be arranged. Eight to fifteen credits.

CHE 960 Research in Chemical Engineering*
Original research leading to the doctoral dissertation. Hours and credits to be arranged.

*By request.

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Biomedical Engineering Courses

BME 503 Physiological Systems
Introduction to mammalian physiology from an engineering point of view. The quantitative aspects of normal cellular and organ functions and the regulatory processes required to maintain organ viability and homeostasis. Note: This course cannot be substituted for BME 482 Engineering Physiology for undergraduate BME majors.

BME 504 Medical Instrumentation and Imaging
Imaging plays a critical role in both clinical and research environments. This course presents both the basic physics and the practical technology associated with such methods as X-ray computed tomography (CT), magnetic resonance imaging (MRI), functional MRI (f-MRI) and spectroscopy, ultrasonics (echocardiography and doppler flow), nuclear medicine (Gallium, PET, and SPECT scans), and optical methods such as bioluminescence, optical tomography, fluorescent confocal microscopy, two-photon microscopy, and atomic force microscopy. Prerequisites: E,306, E,232, and E,246. Cross-listed with CPE 585.

BME 505 Biomaterials
Intended as an introduction to materials science for biomedical engineers, this course first reviews the properties of materials relevant to their application to the human body. It goes on to discuss proteins, cells, tissues, and their reactions and interactions with foreign materials, as well as the degradation of these materials in the human body. The course then treats various implants, burn dressings, drug delivery systems, biosensors, artificial organs, and elements of tissue engineering. Prerequisites: E 306, E 344. Corequisite: BME 506.

BME 506 Biomechanics

This course reviews basic engineering principles governing materials and structures, such as mechanics, rigid body dynamics, fluid mechanics, and solid mechanics, and applies these to the study of biological systems, such as ligaments, tendons, bone, muscles, and joints, etc. The influence of material properties on the structure and function of organisms provides an appreciation for the mechanical complexity of biological systems. Methods for both rigid body and deformational mechanics are developed in the context of bone, muscle, and connective tissue. Multiple applications of Newton's Laws of Mechanics are made to human motion. Prerequisites: E 306, BME 342. Corequisite: BME 505.

BME 557 Sensory Systems
Course focuses on speech, audition, and vision systems. Students will begin with a review of system principles including sampling, filtering, analog to digital conversion (ADC), spectral (Fourier) analysis and transfer functions. The second topic will cover the audio spectrum and properties of sound as they relate to both speech and hearing. The course will then cover basic anatomy and physiology of the larynx, ear, and eye. Students will participate in two types of Labs for each of the three topics. Sensory Labs are designed to enhance the students' knowledge of sound production, auditory response and image processing. Reverse Engineering (RE) Labs utilizing existing speech, hearing, and vision enhancement products will be conducted as well.

BME 600 Strategies and Principles of Biomedical Design
A successful approach to product development and design in the field of medical technologies requires a highly interdisciplinary approach. This course reviews the regulations, protocol, and guidelines which must be met in each discipline, and describes how these issues are inter-related and how they affect design and product development. Marketing, regulatory, IP, and clinical aspects are all considered in the technical aspects of design. Required of all BME M.E. students.

BME 601 Advanced Biomedical Engineering Lab
One of the distinguishing features of biomedical engineers is their ability to make and interpret measurements on living systems. One of the major objectives of advanced laboratory training is to provide experience in selecting appropriate measurement and analysis tools that will advance hypothesis-driven and translational research and development. This laboratory course serves these dual purposes. Students are introduced to techniques for measurements at the cellular, organ, and systems levels. Students will then use these techniques to: (1) formulate hypotheses, design experiments using the tools provided, make appropriate measurements, analyze the data, and determine if the data do or do not support their hypotheses, and (2) make measurements that facilitate

the design and manufacture of devices in terms of materials properties, fatigue, and failure modes. Prerequisites: BME 503, BME 505. Required of all BME M.E. students.

BME 602 Principles of Tissue Engineering
This course is an introduction to the field of Tissue Engineering. It is rapidly emerging as a therapeutic approach to treating damaged or diseased tissues in the biotechnology industry. In essence, new and functional living tissue can be fabricated using living cells combined with a scaffolding material to guide tissue development. Such scaffolds can be synthetic, natural, or a combination of both. This course will cover the advances in the field of cell biology, molecular biology, material science, and their relationship towards developing novel 'tissue engineered' materials.

BME 603 Topics in Biological Transport
The engineering applications of biological transport phenomena are important considerations in basic research related to molecules, organelles, cell, and organ function; the design and operation of devices such as filtration units for kidney dialysis, high density cell cultures, and biosensors; and applications including drug and gene delivery, biological signal transduction, and tissue engineering. This course develops the fundamental principles of transport processes, the mathematical expression of these principles and the solution of transport equations, along with characterization of composition, structure, and function of the living systems to which they are applied.

BME 650 Advanced Biomaterials
Upon completion of this course, students will be able to demonstrate an understanding of the major classes of engineering materials, their principal properties, and design requirements that serve as both the basis for materials selection, as well as for the ongoing development of new materials. This course is substantially differentiated from introductory materials courses by its very specific focus on materials whose use puts them in direct contact with physiological systems. Thus, the course begins with brief sections on inflammatory response, thrombosis, infection, and device failure. It then concentrates on developing the fundamental materials science and engineering concepts underlying the structure-property relationships in both synthetic and natural polymers, metals and alloys, and ceramics relevant to *in vivo* medical-device technology.

BME 655 Principles of Multiscale Biosystems Development and Integration
This course extends concepts presented in tissue engineering, bio-transport, and biomaterials to develop design principles for generating tissue and organs *in vitro*. The processes by which cells, proteins, and extracellular matrix are integrated to form a functioning organ system are developed. The principles of bioreactor design are used to analyze and design *in*

vitro systems for growing functioning tissue and organs for use as prostheses. Principles for scale-up to organs of different size are discussed. Design issues and limitations for extension of these principles to multi-organ systems are illustrated.

BME 665 Pathophysiology
Pathophysiology describes changes in physiology resulting in disease or injury. A solid understanding of normal physiology is necessary before attempting the study of abnormal situations. The course emphasizes the "mechanistic" approach to pathophysiology, i.e. A-B-C, rather than symptom-diagnosis-treatment approach. Multiple examples, case studies, and procedural videos are presented with a discussion of what they do well and where improvements can be made. Prerequisite: A course in human physiology.

BME 675 Nanomedicine
This course will provide a comprehensive introduction to the rapidly developing field of nanomedicine and discuss the application of nanoscience and nanotechnology in medicine such as, in diagnosis, imaging and therapy, surgery, and drug delivery. Prerequisite: NANO 600. Cross-listed with NANO 675.

BME 685 Nanobiotechnology
This course describes the application of nano- and micro-fabrication methods to build tools for exploring the mysteries of biological systems. It is a graduate-level course that will cover the basics of biology and the principles and practice of nano- and microfabrication techniques, with a focus on applications in biomedical and biological research. Prerequisite: NANO 600. Cross-listed with NANO 685.

BME 690 Cellular Signal Transduction
This advanced course covers the mechanism and biological role of signal transduction in mammalian cells. Topics included are extracellular regulatory signals, intracellular signal transduction pathways, role of tissue context in the function of cellular regulation, and examples of biological processes controlled by specific cellular signal transduction pathways. Prerequisites: Undergraduate Cell Biology, Molecular Genetics (Undergraduate). Cross-listed with CH 690.

BME 695 Bio/Nano Photonics
This course deals with the principles of light interactions with biological- and biomedical-relevant systems. The enabling aspects of nanotechnology for advanced biosensing, medical diagnosis, and therapeutically treatment will be discussed. Prerequisites: NANO 600. Cross-listed with CHE 695, MT 695, NANO 695.

BME 700 Seminar in Biomedical Engineering
Lectures by department faculty, guest speakers. and doctoral students on recent research. Enrollment during the entire period of study is required of all full-time

students. No credit. Must be taken every semester. Cross-listed with CHE 700 and MT 700.

BME 701-702 Selected Topics in Biomedical Engineering I - II
Selected topics of current interest in the field of biomedical engineering will be treated from an advanced point of view.

BME 800 Special Problems in Biomedical Engineering
One to three credits. Limit of three credits for the degree of Master of Engineering (Biomedical).

BME 900 Thesis in Biomedical Engineering*
For the degree of Master of Engineering (Biomedical). Nine credits with departmental approval

BME 950 Biomedical Engineering Design Project*
Design project for the degree of Master of Engineering (Biomedical). Hours to be arranged. Six credits, with departmental approval.

BME 960 Research in Chemical Engineering*
Original research leading to the doctoral dissertation. Hours and credits to be arranged.

*By request.

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Materials Engineering Courses

MT 501 Introduction to Materials Science and Engineering
An introduction to the structures/properties relationships of materials principally intended for students with a limited background in the field of materials science. Topics include: structure and bonding, thermodynamics of solids, alloys and phase diagrams, mechanical behavior, electrical properties, and the kinetics of solid state reactions. The emphasis of this subject is the relationship between structure and composition, processing (and synthesis), properties, and performance of materials. For students who do not have a materials undergraduate degree or who wish to familiarize themselves with English terminology.

MT 503 Introduction to Solid State Physics
Description of simple physical models which account for electrical conductivity and thermal properties of solids. Basic crystal lattice structures, X-ray diffraction, and dispersion curves for phonons and electrons in reciprocal space. Energy bands, Fermi surfaces, metals, insulators, semiconductors, superconductivity, and ferromagnetism. Fall semester. Typical text: Kittel, *Introduction to Solid State Physics*. Prerequisites: PEP 242 and PEP 331 or equivalent. Cross-listed with EE 503 and PEP 503.

MT 505 Introduction to Biomaterials

Intended as an introduction for the student who is familiar with materials science, this course first reviews the properties of materials that are relevant to their application in the human body. It then introduces proteins, cells, tissues, and their reactions to foreign materials, and the degradation of these materials in the human body. The course then treats the various implants, burn dressings, drug delivery systems, biosensors, artificial organs, and elements of tissue engineering. Cross-listed with BME 505. Prerequisite: MT 501 or equivalent.

MT 506 Mechanical Behavior of Solids
Theory and practical means for predicting the behavior of materials under stress. Elastic and plastic deformation, fracture, and high-temperature deformation (creep).

MT 507 Introduction to Microelectronics and Photonics
An overview of microelectronics and photonics science and technology. It provides students who wish to specialize in his/her application, physics, or fabrication with the necessary knowledge of how the different aspects are interrelated. It is taught in three modules: design and applications, taught by EE faculty; operation of electronic and photonic devices, taught by physics faculty; and fabrication and reliability, taught by the materials faculty. Cross-listed with EE 507 and PEP 507.

MT 515-516 Photonics I-II
This course will cover topics encompassing the fundamental subject matter for the design of optical systems. Topics will include optical system analysis, optical instrument analysis, applications of thin film coatings, and opto-mechanical system design in the first term. The second term will cover the subjects of photometry and radiometry, spectrographic and spectrophotometric systems, infrared radiation measurement and instrumentation, lasers in optical systems, and photon-electron conversion. Prerequisite: PEP 209 or PEP 509. Cross-listed with PEP 515-516 and EE 515-516.

MT 520 Composite Materials
Composite material characterization; composite mechanics of plates, panels, beams, columns, and rods integrated with design procedures; analysis and design of composite structures; joining methods and procedures; introduction to manufacturing processes of filament winding, braiding, injection, compression and resin transfer molding, machining and drilling; and industrial applications. Cross-listed with ME 520.

MT 525 Techniques of Surface Analysis**
Lectures, demonstrations, and laboratory experiments, selected from among the following topics, depending on student interest: vacuum technology; thin-film preparation; scanning electron microscopy; LEED; infrared spectroscopy, and ellipsometry; electron

spectroscopies (Auger, photoelectron, and field emission); and ion spectroscopies (SIMS, IBS, and surface properties-area), roughness, and surface tension.

MT 544 Introduction to Electron Microscopy**

A lecture and laboratory course that introduces basic concepts in the design and operation of transmission electron microscopes and scanning electron microscopes, as well as the fundamental aspects of image interpretation and diffraction analysis. Topics include: electron sources, electron optics, kinematic and dynamic theory of electron diffraction, and spectroscopic analysis. A typical textbook is Goodhew and Humphreys, *Electron Microscopy and Analysis*.

MT 545 Plasma Processing

Basic plasma physics; some atomic processes; and plasma diagnostics. Plasma production; DC glow discharges, and RF glow discharges; and magnetron discharges. Plasma-surface interaction; sputter deposition of thin films; reactive ion etching, ion milling and texturing, and electron-beam-assisted chemical vapor deposition; and ion implantation. Sputtering systems; ion sources; electron sources; and ion beam handling. Typical text: Chapman, *Glow Discharge Processes*; Brodie, Muray, *The Physics of Microfabrication*. Taught jointly with PEP 545.

MT 561 Solid State Electronic for Engineering I

This course introduces fundamentals of semiconductors and basic building blocks of semiconductor devices that are necessary for understanding semiconductor device operations. It is for first-year graduate students and upper-class undergraduate students in electrical engineering, applied physics, engineering physics, optical engineering, and materials engineering who have no previous exposure to solid state physics and semiconductor devices. Topics covered will include: description of crystal structures and bonding; introduction to statistical description of electron gas; free-electron theory of metals; motion of electrons in periodic lattices-energy bands; Fermi levels; semiconductors and insulators; electrons and holes in semiconductors; impurity effects; generation and recombination; mobility and other electrical properties of semiconductors; thermal and optical properties; p-n junctions; and metal-semiconductor contacts.
Cross-listed with PEP 561 and EE 561.

MT 562 Solid State Electronic for Engineering II

This course introduces operating principles and develops models of modern semiconductor devices that are useful in the analysis and design of integrated circuits. Topics covered include charge carrier transport in semiconductors; diffusion and drift; injection and lifetime; p-n junction devices; bipolar junction transistors; metal-oxide-semiconductor field effect transistors and high electron mobility transistors; microwave devices; light-emitting diodes, semiconductor lasers, and photodetectors; and integrated devices. Cross-listed with PEP 562 and EE 562.

MT 585 Physical Design of Wireless Systems
Physical design of wireless communication systems, emphasizing present, and next-generation architectures. Impact of non-linear components on performance; noise sources and effects; interference; optimization of receiver and transmitter architectures; individual components (LNAs, power amplifiers, mixers, filters, VCOs, phase-locked loops, frequency synthesizers, etc.); digital signal processing for adaptable architectures; analog-digital converters; new component technologies (SiGe, MEMS, etc.); specifications of component performance; reconfigurability and the role of digital signal processing in future generation architectures; direct conversion; RF packaging; and minimization of power dissipation in receivers. Cross-listed with EE 585 and PEP 585.

MT 595 Reliability and Failure of Solid State Devices
This course deals with the electrical, chemical, environmental, and mechanical driving forces that compromise the integrity and lead to the failure of electronic materials and devices. Both chip- and packaging-level failures will be modeled physically and quantified statistically in terms of standard reliability mathematics. On the packaging level, thermal stresses, solder creep, fatigue and fracture, contact relaxation, corrosion, and environmental degradation will be treated. Prerequisite: MT 507. Cross-listed with PEP 595 and EE 595.

MT 596 Microfabrication Techniques
Deals with aspects of the technology of processing procedures involved in the fabrication of microelectronic devices and microelectromechanical systems (MEMS). Students will become familiar with various fabrication techniques used for discrete devices as well as large-scale integrated thin film circuits. Students will also learn that MEMS are sensors and actuators that are designed using different areas of engineering disciplines and they are constructed using a microlithographically-based manufacturing process in conjunction with both semiconductor and micro-machining microfabrication technologies. Prerequisite: MT 507. Cross-listed with EE 596 and PEP 596.

MT 601 Structure and Diffraction
Crystal structures, point defects, dislocations, slip systems, grain boundaries, and microstructures. Scattering of X-rays and electrons, diffraction by single and polycrystalline materials and its application to material identification, crystal orientation, texture determination, strain measurement, and crystal structure analysis.

MT 602 Principles of Inorganic Materials Synthesis
The goal of this course is to learn the basic concepts commonly utilized in the processing of advanced materials with specific compositions and microstructures. Solid state diffusion mechanisms are described with emphasis on the role of point defects, the mobility of diffusing atoms, and their interactions. Macroscopic diffusion phenomena are analyzed by formulating partial differential equations and presenting their solutions. The relationships between processing and microstructure are developed on the basis of the rate of nucleation and growth processes that occur during condensation, solidification, and precipitation. Diffusionless phase transformations observed in certain metallic and ceramic materials are discussed. Prerequisite: MT 603.

MT 603 Thermodynamics and Reaction Kinetics of Solids
The principal areas of concentration include a review of thermodynamic laws applying to closed systems, chemical potentials and equilibria in heterogeneous systems, fugacity, activity functions, solution thermodynamics, multicomponent metallic solutions, the thermodynamics of phase diagrams, and phase transformations.

MT 626 Optical Communication Systems
Components for and design of optical communication systems; propagation of optical signals in single mode and multimode optical fibers; optical sources and photodetectors; optical modulators and multiplexers; optical communication systems: coherent modulators, optical fiber amplifiers and repeaters, and transcontinental and transoceanic optical telecommunication system design; and optical fiber local area networks. Cross-listed with PEP 626, EE 626, and NIS 626.

MT 650 Special Topics in Materials Science and Engineering
Selected topics in surface modification and coatings technology, such as chemical vapor deposition, physical vapor deposition, ion implantation, or others. Description of the processing techniques, characterization, and performance evaluation of the surfaces.

MT 670 Polymer Properties and Structure
Stress-strain relationships, theory of linear viscoelasticity and relaxation spectra, temperature dependence of viscoelastic behavior, dielectric properties, dynamic mechanical and electrical testing, molecular theories of flexible chains, statistical mechanics and thermodynamics of rubber-like undiluted systems, and morphology of high polymers. Cross-listed with CHE 670.

MT 690 Introduction to VLSI Design

This course introduces students to the principles and design techniques of very large scale integrated circuits (VLSI). Topics include: MOS transistor characteristics, DC analysis, resistance, capacitance models, transient analysis, propagation delay, power dissipation, CMOS logic design, transistor sizing, layout methodologies, clocking schemes, and case studies. Students will use VLSI CAD tools for layout and simulation. Selected class projects may be sent for fabrication. Cross-listed with CPE 690 and PEP 690.

MT 700 Seminar in Materials Engineering
Lectures by department faculty, guest speakers, and doctoral students on recent research. Enrollment during the entire period of study is required of all full-time students. No credit. Must be taken every semester. Cross-listed with CHE 700 and BME 700.

MT 800 Special Problems in Materials*
One to six credits. Limit of six credits for the degree of Master of Engineering.

MT 801 Special Problems in Materials*
One to six credits. Limit of six credits for the degree of Doctor of Philosophy.

MT 900 Thesis in Materials
Research for the degree of Master of Science or Master of Engineering. Five to ten credits with departmental approval. More than five credits requires a second reader.

MT 960 Research in Materials
Original research leading to the doctoral dissertation. Hours and credits to be arranged.

*By request.
**Offered alternate semesters.

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Nanotechnology

NANO 600 Nanoscale Science and Technology
This course deals with the fundamentals and applications of nanoscience and nanotechnology. Size-dependent phenomena, ways and means of designing and synthesizing nanostructures, and cutting-edging applications will be presented in an integrated and interdisciplinary manner.

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