# ELECTRICAL ENGINEERING

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Courses given in Electrical Engineering have the subject code EE. For a complete list of subject codes, see Appendix.

## UNDERGRADUATE PROGRAMS

The mission of the Undergraduate Program of the Department of Electrical Engineering is to augment the liberal education expected of all Stanford undergraduates and impart a basic understanding of electrical engineering built on a foundation of physical science, mathematics, computing, and technology.

Graduates of the undergraduate program are expected to possess knowledge of the fundamentals of electrical engineering and of at least one specialty area. The graduates are expected to have the basic experimental, design, and communication skills to be prepared for continued study at the graduate level or for entry level positions that require a basic knowledge of electrical engineering, science, and technology.

The educational objectives of the program are:

1. Technical Knowledge: provide a basic knowledge of electrical engineering principles along with the required supporting knowledge of computing, engineering fundamentals, mathematics, and science. The program must include depth in at least one specialty area, currently including Computer Hardware, Computer Software, Controls, Circuits, Fields and Waves, and Communication and Signal Processing.
2. Laboratory and Design Skills: develop the basic skills needed to perform and design experimental projects. Develop the ability to formulate problems and projects and to plan a process for solution, taking advantage of diverse technical knowledge and skills.
3. Communications Skills: develop the ability to organize and present information and to write and speak effective English.
4. Preparation for Further Study: provide sufficient breadth and depth for successful subsequent graduate study, post-graduate study, or lifelong learning programs.
5. Preparation for the Profession: provide an appreciation for the broad spectrum of issues arising in professional practice, including economics, ethics, leadership, professional organizations, safety, service, and teamwork.

To specialize in Electrical Engineering (EE), undergraduate students should follow the depth sequence given in the discussion of undergraduate programs in the "School of Engineering" section of this bulletin. Students are required to have a program planning sheet approved by their adviser and the department prior to the end of the quarter following the quarter in which they declare their major and at least one year prior to graduation. Program sheets for the general EE requirements and for each of the EE specialty sequences may be found at http://ughb.stanford.edu. Majors must receive at least a 2.0 grade point average (GPA) in courses taken for the EE depth requirement and all classes must be taken for a letter grade.

For information about an EE minor, see the "School of Engineering" section of this bulletin.

A Stanford undergraduate may work simultaneously toward the B.S. and M.S. degrees. See "Dual and Coterminal Degree Programs" in the "School of Engineering" section of this bulletin.

For University coterminal degree program rules and University application forms, see http://registrar.stanford.edu/publications/#Coterm.

## HONORS

The Department of Electrical Engineering offers a program leading to a Bachelor of Science in Electrical Engineering with honors. This program offers a unique opportunity for qualified undergraduate majors to conduct independent study and research at an advanced level with a faculty mentor, graduate students, and fellow undergraduates.

Admission to the honors program is by application. Declared EE students with a grade point average (GPA) of at least 3.5 in Electrical Engineering are eligible to submit an application. Applications must be submitted by Autumn quarter of the senior year, be signed by the thesis adviser and second reader (one must be a member of the EE Faculty), and include an honors proposal.

In order to receive departmental honors, students admitted to the honors program must:

1. maintain a grade point average (GPA) of at least 3.5 in Electrical Engineering courses
2. complete at least 10 units of EE 191 for a letter grade with their project adviser
3. submit two final copies of the honors thesis approved by the adviser and second reader
4. attend poster and oral presentation in the Electrical Engineering Honors Symposium held at the end of Spring Quarter or present in another suitable forum approved by the faculty adviser.

## GRADUATE PROGRAMS

University regulations governing the M.S., Engineer, and Ph.D. degrees are described in the "Graduate Degrees" section of this bulletin.

The profession of electrical engineering demands a strong foundation in physical science and mathematics, a broad knowledge of engineering techniques, and an understanding of the relationship between technology and man. Curricula at Stanford are planned to offer the breadth of education and depth of training necessary for leadership in the profession. To engage in this profession with competence, four years of undergraduate study and at least one year of postgraduate study are recommended. For those who plan to work in highly technical development or fundamental research, additional graduate study is desirable.

A one- to two-year program of graduate study in Electrical Engineering may lead to the degree of Master of Science. The program is typically completed in four academic quarters. A two- to three-year program, offering a wider selection of engineering course work, more opportunity for study in the related fields of engineering, mathematics, and physics, and in particular, more independent work and individual guidance, may lead to the degree of Engineer.

The degree of Doctor of Philosophy is offered under the general regulations of the University. The doctoral program, requiring a minimum of 135 units of graduate study, should be considered by those with the ability and desire to make a life work of research or teaching.

*Application for Admission*—Applications for admission with graduate standing in Electrical Engineering (EE) should be completed electronically at http://gradadmissions.stanford.edu. If you do not have access to the web, a printed application can be obtained by writing to the Graduate Admissions, Office of the University Registrar, 520 Lasuen Mall, Old Union Building, Stanford, CA 94305-3005. The application deadline for admission for Autumn Quarter 2005-06 is December 14, 2004.

## MASTER OF SCIENCE

Modern electrical engineering is a broad and diverse field, and graduate education in this department may satisfy a variety of objectives. Students with undergraduate degrees in physics, mathematics, or related sciences, as well as in various branches of engineering, are invited to apply for admission. They will ordinarily be able to complete the master's degree in five academic quarters; students should be aware that many courses are not taught during the summer. Students with undergraduate degrees in other fields may also be admitted for graduate study (see below).

The master's degree program may provide advanced preparation for professional practice or for teaching on the junior college level, or it may serve as the first step in graduate work leading to the degree of Engineer or Ph.D. The faculty does not prescribe specific courses to be taken. Each student, with the help of a program adviser, prepares an individual program and submits it to the faculty for approval. The master's program proposal must be submitted to the department office during the first quarter of graduate study; modifications may be made later. Detailed requirements and instructions are in the *Handbook for Graduate Students in Electrical Engineering at Stanford University* (http://ee.stanford.edu/gradhandbook/). Programs of at least 45 quarter units that meet the following guidelines are normally approved:

1. A sequence of three or more graded electrical engineering courses numbered above 200, to provide depth in one area. The student must maintain an average 3.0 grade point average (GPA) or better in both the depth area and overall.
2. At least one graded EE course numbered above 200 in each of three distinct course areas outside of the area selected under item 1 to provide breadth. Two courses are not considered to be in distinct areas if they can be found under a common depth area.
3. Enough additional units of electrical engineering courses so that items 1 through 3 total at least 21 units of graded EE courses numbered above 200, including at least 9 units of such courses numbered in the 300s or 400s. Some 600- or 700-level summer courses may also be considered for inclusion in the M.S. program. Special studies units may not be used.
4. Additional course work to bring the total to 45 or more quarter units, including:
   a) at least 36 graded units
   b) at least 36 units at or above the 100 level
   c) at least 30 units in technical areas such as engineering, mathematics, and science; thesis and special studies units cannot be included among these 30 units.
5. The EE 201A seminar in Autumn Quarter and either (a) at least one formal seminar course for credit, or (b) attend a minimum of eight informal or formal research seminars, and submit with the final M.S. program a list of the seminars with a paragraph describing the content and the signature of the M.S. adviser. This requirement is to ensure that all students sample the many available research seminars. In case of conflict with EE 201A, tapes may be viewed in the Terman Library.

Capable students without formal undergraduate preparation in electrical engineering may also be admitted for graduate study. Such students may have graduated in any field and may hold either the B.S. or B.A. degree. Each student, with the help of an adviser, prepares a program of study to meet his or her particular needs and submits it to the faculty for approval. A student with adequate preparation in mathematics through calculus and college physics including electricity can usually complete the M.S. degree requirements within two academic years. A student with some additional preparation in electrical engineering may be able to complete the M.S. requirements in only one academic year.

Graduate study in electrical engineering demands that students be adequately prepared in circuits, digital systems, fields, lab work, mathematics, and physics. Skill in using modern computing facilities is essential for electrical engineers, and an increasing number of courses routinely require it. Skill should be acquired early in the program, either by taking one of the regular computer science courses or one of the special short courses given by the Computation Center, or by self-study.

It is the student's responsibility, in consultation with an adviser, to determine whether the prerequisites for advanced courses have been met. Prerequisite courses ordinarily taken by undergraduates may be included as part of the graduate program of study. However, if the number of these is large, the proposed program should contain more than the typical 45 units, and the time required to meet the degree requirements may be increased.

Permission to study beyond the M.S. degree must be obtained from the department (if possible, well before the M.S. degree is received). The student needs to file a Graduate Program Authorization Petition. Permission is predicated on the applicant's academic record, performance in independent work, potential for advanced study, and on the ability of the faculty to supervise such study. For the most recent information, see http://ee.stanford.edu/gradhandbook/ms.html.

## ENGINEER

The degree of Engineer requires a minimum of 90 units of residency. Units completed at Stanford towards a master's degree in an Engineering discipline may be used towards the 90-unit residency requirement for the Engineer degree. A student who received an M.S. degree elsewhere can transfer in 45 units towards the 90-unit requirement for an Engineer's degree. A student would need to fill out the Application for Graduate Residency Credit form to be filed with the Degree Progress Office in the Registrar's Office, Old Union Building.

Work toward the degree of Engineer in Electrical Engineering normally includes the requirements for work toward the master's degree in Electrical Engineering, including qualifications for admission.

An additional year allows time for a broader program, or a more concentrated program, or whatever arrangement may seem suitable to the candidate, his adviser, and the department. Advanced study at other universities, or in other departments at Stanford, may be allowed within the foregoing consideration. The equivalent of approximately one quarter is devoted to independent study and thesis work with faculty guidance. The thesis is often of the nature of a professional report on the solution of a design problem. The degree of Engineer differs from the Ph.D. in that it prepares for professional engineering work rather than theoretical research. The candidate may select courses that are suitable for either the degree of Engineer or the Ph.D. degree and decide later which program to pursue.

The best procedure for the applicant to follow is (1) if now working toward the Stanford M.S. degree in Electrical Engineering, request permission to continue graduate studies beyond the master's degree, using the Graduate Program Authorization Petition form obtained from the Department of Electrical Engineering office, or (2) if not planning to receive the Stanford M.S. degree in Electrical Engineering, apply for admission to the Department of Electrical Engineering as a candidate for the degree of Engineer.

During the first quarter of work beyond the M.S. degree, formal application for admission to candidacy for the degree of Engineer is made on a form that can be obtained from the department office. The program of study is prepared by the student with the help of the thesis adviser and submitted to the academic associate for approval. The form should contain a list of all graduate courses completed at Stanford and elsewhere and all courses yet to be completed. For the most recent information, see http://ee.stanford.edu/gradhandbook/engineer.html.

## DOCTOR OF PHILOSOPHY

Admission to a graduate program does not imply that the student is a candidate for the Ph.D. degree. Advancement to candidacy requires superior academic achievement, satisfactory performance on a qualifying examination, and sponsorship by two faculty members. Enrollment in EE 391, Special Studies, is recommended as a means for getting acquainted with a faculty member who might be willing to serve as a supervisor.

Students in the Ph.D. program should submit an application to take the department qualifying examination (given each Winter Quarter). Upon successful completion of the qualifying examination and after securing agreement by two faculty members to serve as dissertation advisers, the student should file an Application for Doctoral Candidacy. The Ph.D. in Electrical Engineering is a specialized degree, and is built on a broad base of physics, mathematics, and engineering skills. The course program is expected to reflect competency in Electrical Engineering and specialized study in other areas relevant to the student's research focus. Normally the majority of units are drawn from EE department courses, with typically 9 units from related advanced physics, mathematics, engineering, or computer science courses, depending on the area of research. Only after receiving department approval to that application does the student become a candidate for the Ph.D. degree.

Requirements may be summarized as follows. The student must complete (1) a minimum of 135 units of residence with graduate standing at Stanford; (2) one or more qualifying examinations given by the faculty of the Department of Electrical Engineering; (3) an approved course of study in electrical engineering; (4) an approved program of research and a written dissertation, based on research, which must be a contribution to knowledge; (5) an oral examination that is a defense of dissertation research and is taken near the completion of the doctoral program.

### PH.D. MINOR

For a minor in Electrical Engineering (EE), the student must fulfill the M.S. depth requirement, complete a total of at least 20 units of course work at the 200-plus level in electrical engineering (of which 15 units must be graded) and be approved by the department's Ph.D. Degree Committee. A grade point average (GPA) of at least 3.35 on these courses is required.

## FINANCIAL ASSISTANCE

The department awards a limited number of fellowships, teaching and course assistantships, and research assistantships to incoming graduate students. Applying for such assistance is part of filling out and submitting the admission application.

## THE HONORS COOPERATIVE PROGRAM

Many of the department's graduate students are supported by the Honors Cooperative Program (HCP), which makes it possible for academically qualified engineers and scientists in nearby companies to be part-time graduate students in Electrical Engineering while continuing nearly full-time professional employment. Prospective HCP students follow the same admission process and must meet the same admission requirements as full-time graduate students. For more information regarding the Honors Cooperative Program, see the "School of Engineering" section of this bulletin.

## AREAS OF RESEARCH

Candidates for advanced degrees participate in the research activities of the department as paid research assistants or as students of individual faculty members. At any one time, certain areas of research have more openings than others. A new applicant should express a second choice of research interest in the event that there are no vacancies in the primary area of interest. At present, faculty members and students are actively engaged in research in the areas listed below.

### COMMUNICATIONS

Adaptive Modulation and Coding
Adaptive Multiuser Coding and Reception
Applied Optics and Optoelectronics
Cellular Radio Systems/Networks
Coding and Coded Modulation
Communication Channels and Signal Propagation
Communication and Information Theory
Digital Subscriber Lines
Digital Transmission
Frequency Reuse in Large Wireless Networks
Mobility in Wireless Networks
Multicarrier Modulation and OFDM
Multipath Mitigation Techniques
Multiple Access Techniques
Multiple Antenna and MIMO Systems
Optical Communications
Optical Networks
Optoelectronic Components and Systems
Resource Allocation/Channel Assignment/Handoff in Wireless Networks
Wavelength Division Multiplexing
Wireless Ad-Hoc Networks
Wireless Communications
Wireless Local Area Networks
Wireless Personal Communication Systems

## COMPUTER SYSTEMS

Asynchronous Circuits
Compilers
Computer-Aided Design
Computer Architecture
Computer Graphics
Computer Networks
Computer Organization
Computer Reliability
Concurrent Languages
Concurrent Processes and Processors
Database and Information Systems
Distributed Systems
Embedded System Design
Hardware/Software Co-Design
Hardware Verification
Human Computer Interaction
Multimedia Systems
Operating Systems
Performance Measurement and Modeling
Programming Languages
Program Verification
VLSI Design

## INFORMATION SYSTEMS

Adaptive Control and Signal Processing
Adaptive Neural Networks
Biomedical Signal Analysis
Computer-Aided Design and Analysis of Systems
Data Communications
Digital Signal Processing
Estimation Theory and Applications
Fourier and Statistical Optics
Information and Coding Theory
Medical Imaging and Image Processing
Multivariable Control
Optical Communications
Optimization-Based Design
Pattern Recognition and Complexity
Quantization and Data Compression
Real-Time Computer Applications
Signal Processing
Speech and Image Coding

## INTEGRATED CIRCUITS

Analog Integrated Circuits
Bipolar, MOS, and other Device and Circuit Technologies
CAD of Processes, Devices, and Equipment
Custom Integrated Circuits for Computers and Telecommunications
Digital Integrated Circuits
Integrated Sensors and Actuators
Mixed Signal Integrated Circuits
Nanostructures
Optoelectronic Integrated Circuits
Process, Device, Circuit, and Equipment Modeling
Sensors and Control for VLSI Manufacturing
VLSI Device Structures and Physics
VLSI Fabrication Technology
VLSI Materials, Interconnections, and Contacts
VLSI Packaging and Testing

## LASERS AND QUANTUM ELECTRONICS

Coherent UV and X-Ray Sources
Free-Electron Lasers
Laser Applications in Aeronautics, Biology, Chemistry, Communications, Electronics, and Physics
Laser Devices and Laser Physics
Nonlinear Optical Devices and Materials
Optoelectronic Devices
Photoacoustic Phenomena
Semiconductor Diode Lasers
Ultrafast Optics and Electronics

## MICROWAVES, ACOUSTICS, AND OPTICS

Acoustic Microscopy
Acousto-Optic Devices
Fiber Optics
Holography
Microwave Integrated Circuits and Devices
Nanophotonics
Nondestructive Testing
Optical Interferometry
Scanning Optical Microscopes

## RADIOSCIENCE AND REMOTE SENSING

Environmental Studies using Satellite Technology
Exploration of the Earth from Space
Interferometric and Holographic Imaging with Radio Waves
Numerical Methods for Science Data Analysis
Optical Remote Sensing
Planetary Exploration
Radar Interferometry
Radar Remote Sensing
Radio Occultation Studies
Radio Wave Scattering
Remote Sensing of Atmospheres and Surfaces
Signal and Image Processing Methods
Space Data Management
Spaceborne Radio Receiver Development
Synthetic Aperture Radar Satellites

## SOLID STATE

Applied and Fundamental Superconductivity
Crystal Preparation: Epitaxy and Ion Implantation, and Molecular Beam Epitaxy
Defect Analysis in Semiconductors
Electron and Ion Beam Optics
Electron Spectroscopy
Experimental Determination of the Electronic Structure of Solids
High Resolution Lithography
Laser, Electron, and Ion Beam Processing and Analysis
Magnetic Information Storage
Magnetic Materials Fundamentals and Nanostructures
Nanostructure Fabrication and Applications
Nanophotonics
Molecular Beam Epitaxy
Novel Packaging Approaches for Electronic Systems
Optoelectronic Devices
Physics and Chemistry of Surfaces and Interfaces
Semiconductor and Solid State Physics
Solid State Devices: Physics and Fabrication
Ultrasmall Electron and Photodevices

## SPACE PHYSICS AND ELECTROMAGNETICS

Computational Electromagnetics
Detection of Electromagnetic Fields from Earthquakes
Electromagnetic Waves and Plasmas
Geomagnetically Trapped Radiation
Ionospheric and Magnetospheric Physics
Ionospheric Modification
Lightning Discharges
Lightning-Ionosphere Interactions
Space Engineering (also see the “Space Science and Astrophysics” section of this bulletin)
Ultra-Low Frequency Fluctuations of the Earth’s Magnetic Field
Very Low Frequency Wave Propagation and Scattering

## COURSES

WIM indicates that the course satisfies the Writing in the Major requirements. (AU) indicates that the course is subject to the University Activity Unit limitations (8 units maximum).

Electrical Engineering courses are typically numbered according to the year in which the courses are normally taken.

020-099 first or second year
100-199 second through fourth year
200-299 mezzanine course for advanced undergraduates or graduates
300-399 first graduate year
400-499 second or third graduate year
600-799 special summer courses

The Department of Electrical Engineering (EE) offers courses in the following areas:

- Circuits
- Communication Systems
- Computer Hardware
- Computer Software Systems
- Control and Systems Engineering
- Dynamic Systems and Optimization
- Electronic Devices, Sensors, and Technology
- Fields, Waves, and Radioscience
- Image Systems
- Lasers, Optoelectronics, and Quantum Electronics
- Network Systems
- Signal Processing
- Solid State Materials and Devices
- VLSI Design

## UNDERGRADUATE

**EE 10N. How Musical Instruments Work**—Stanford Introductory Seminar. Preference to freshman. Musical instruments as examples of science, engineering, and the interplay between the two. The principles of operation of wind, string, percussion, and electronic instruments. Concepts include waves, resonators, sound spectra and the harmonic structure of instruments, engineering design, and the historical co-development of instruments and the science and engineering that makes them possible. Prerequisites: high school math and physics. Recommended: some experience playing a musical instrument. GER:2b

*3 units, Spr (Miller)*

**EE 12N. How Cyberspace Works**—Stanford Introductory Seminar. Preference to freshman. Introduction to information technology. The technical foundation of bits and bytes, multimedia, and networks, using the web as a starting point. Topics include representing information as bits and bytes, digital music, images, video, computer graphics, and virtual reality. Data compression, JPEG, MPEG audio, and video. Bandwidth and sampling. Analog, digital, and wireless telephone systems. Digital transmission and storage: modulation, error control; cable, fiber, satellite, storage media. Broadcasting. GPS. Circuit- versus packet-switched networks, local-area networks, Ethernet, Internet. Email, VoIP. Security: encryption, digital signatures, digital certificates. Field-trip to a Silicon Valley information technology company. GER:2b

*3 units, Win (Girod)*

**EE 14N. Things about Stuff**—Stanford Introductory Seminar. Preference to freshman. Most engineering curricula present truncated, linear histories of technology, but the stories behind disruptive inventions such as the telegraph, telephone, wireless, television, transistor, and chip are as important as the inventions themselves. How these stories elucidate broadly applicable scientific principles. Focus is on studying consumer devices; optional projects to build devices including semiconductors made from pocket change. Students may propose topics of interest to them. GER:2b

*3 units, Aut (Lee)*

**EE 41. Physics of Electrical Engineering**—How everything from electrostatics to quantum mechanics is used in common high-technology products. Electrostatics are critical in micro-mechanical systems used in many sensors and displays, and basic EM waves are essential in all high-speed communication systems. How to propagate energy in free space. Which aspects of modern physics are needed to generate light for the operation of a DVD player or TV. Introduction to semiconductors, solid-state light bulbs, and laser pointers. Hands-on labs to connect physics to everyday experience. GER:2b

*5 units, Win (Solgaard, Miller)*

**EE 45. Science and Technology in WW II and What Happened Afterward**—The efforts of engineers, mathematicians, and scientists during WWII. The effect on the postwar world in areas such as information, communication, transportation, materials, and medicine. Science and engineering in the war effort, and what became of them after the war, drawn from: encryption and computation; radar, communication, and electronics; control and optimization; materials; drugs and medicine. GER:2b

*3 units, Spr (Osgood)*

**EE 60Q. Man versus Nature: Coping with Disaster Using Space Technology**—(Same as GEOPHYS 60Q.) Stanford Introductory Seminar. Preference to sophomores. Natural hazards (earthquakes, volcanoes, floods, hurricanes, and fires) affect thousands of people everyday. Disasters such as asteroid impacts periodically obliterate many species of life. Spaceborne imaging technology makes it possible to respond quickly to such threats to mitigate consequences. How these new tools are applied to natural disasters, and how remotely sensed data are manipulated and analyzed. Basic scientific issues, political and social consequences, costs of disaster mitigation, and how scientific knowledge affects policy. GER:2b

*3 units, Aut (Zebker)*

**EE 100. The Electrical Engineering Profession**—Lectures/discussions on topics of importance to the electrical engineering professional. Continuing education, professional societies, intellectual property and patents, ethics, entrepreneurial engineering, and engineering management.

*1 unit, Aut (Gray)*

**EE 101A. Circuits I**—First of two-course sequence. Introduction to circuit modeling and analysis. Topics include creating the models of typical components in electronic circuits and simplifying non-linear models for restricted ranges of operation (small signal model); and using network theory to solve linear and non-linear circuits under static and dynamic operations. GER:2b

*4 units, Win (Wong)*

**EE 101B. Circuits II**—Second of two-course sequence. MOS large-signal and small-signal models. MOS amplifier design including DC bias, small signal performance, multistage amplifiers, frequency response, and feedback. Prerequisite: 101A. GER:2b

*4 units, Aut, Spr (Shenoy)*

**EE 102A. Signal Processing and Linear Systems I**—Concepts and mathematical tools in continuous-time signal processing and linear systems analysis, illustrated with examples from signal processing, communications, and control. Mathematical representation of signals and systems. Linearity and time-invariance. System impulse and step response. Frequency domain representations: Fourier series and Fourier transforms. Filtering and signal distortion. Time/frequency sampling and interpolation. Continuous-discrete time signal conversion and quantization. Stability and causality in linear systems. Laplace transforms and Bode plots. Feedback and control system design. Examples from filter design and linear control. GER:2b

*4 units, Win (Pauly, Gray)*

**EE 102B. Signal Processing and Linear Systems II**—Concepts and mathematical tools in discrete-time signal processing and linear systems analysis with examples from digital signal processing, communications, and control. Discrete-time signal models. Continuous-discrete-continuous signal conversion. Discrete-time impulse and step response. Frequency domain representations: Fourier series and transforms. Connection between continuous and discrete time frequency representations. Discrete Fourier transform (DFT) and fast Fourier transform (FFT). Digital filter and signal processing examples. Discrete-time and hybrid linear systems. Stability and causality. Z transforms and their connection to Laplace transforms. Frequency response of discrete-time systems. Discrete-time control. Prerequisite: 102A. GER:2b

*4 units, Spr (Girod)*

**EE 105. Feedback Control Design**—(Enroll in ENGR 105.)

*3 units, Win (Rock)*

**EE 106. Planetary Exploration**—The other worlds of the solar system as revealed by their electromagnetic emissions and, in particular, by recent space missions. Planetary interiors, surfaces, atmospheres, moons, and rings and with the interplanetary environment, including its gas, dust, meteors, and comets. Stanford EE Department radio experiments have been a part of every major NASA planetary probe and this experience provides a unique point of view. Prerequisite: One year of college engineering. GER:2b

*3 units, Spr (Fraser-Smith)*

**EE 108A. Digital Systems I**—Digital circuit, logic, and system design. Digital representation of information. CMOS logic circuits. Combinational logic design. Logic building blocks, idioms, and structured design. Sequential logic design and timing analysis. Clocks and synchronization. Finite state machines. Microcode control. Digital system design. Control and datapath partitioning. Lab. Prerequisite: ENGR 40. Corequisite for WIM: ENGR 102E. GER:2b,WIM

*4 units, Aut (Le), Win (Dally)*

**EE 108B. Digital Systems II**—The design of processor-based digital systems. Instruction sets, addressing modes, data types. Assembly language programming, low-level data structures, introduction to operating systems and compilers. Processor microarchitecture, microprogramming, pipelining. Memory systems and caches. Input/output, interrupts, buses and DMA. System design implementation alternatives, software/hardware tradeoffs. Labs involve the design of processor subsystems and processor-based embedded systems. Prerequisite: 108A, CS 106B. GER:2b

*4 units, Win (Olukotun), Spr (Kozyrakis)*

**EE 109. Digital Systems Design Lab**—The design of integrated digital systems encompassing both customized software and hardware. Software/hardware design tradeoffs. Algorithm design for pipelining and parallelism. System latency and throughput tradeoffs. FPGA optimization techniques. Integration with external systems and smart devices. Firmware configuration and embedded system considerations. Enrollment limited to 25; preference to graduating seniors. Prerequisites: 108B, and CS 106B or X. GER:2b

*4 units, Win (Black-Shafer)*

**EE 116. Semiconductor Device Physics**—The fundamental operation of semiconductor devices and overview of applications. The physical principles of semiconductors, both silicon and compound materials; operating principles and device equations for junction devices (diodes, bipolar transistor, photo-detectors). Introduction to quantum effects and band theory of solids. Prerequisite: ENGR 40. Corequisite: 101A. GER:2b

*3 units, Spr (Peumans, Dutton)*

**EE 122. Analog Circuits Laboratory**—Introduces the practical applications of analog circuits, including simple amplifiers, filters, oscillators, power supplies, and sensors. Goals: lab experience, basic design skills, experience with computer-aided design, and basic circuit fabrication/debugging knowledge. Students work in teams of two to learn the design process through proposing, designing, simulating, building, debugging, and demonstrating a suitable project. Prerequisite: ENGR 40 or equivalent. GER:2b

*3 units, Aut, Spr (Kovacs)*

**EE 133. Analog Communications Design Laboratory**—The design and testing of analog communications circuits, including applications. Amplitude Modulation (AM) using multiplier circuits. Frequency Modulation (FM) based on discrete oscillator and integrated modulator circuits such as voltage-controlled oscillators (VCOs). Phased-lock loop (PLL) techniques, characterization of key parameters and their applications. Practical aspects of circuit implementations. Labs involve the systematic building and characterization of AM and FM modulation/demodulation circuits and subsystems. Enrollment limited to 30 undergraduate and coterminal EE students. Prerequisites: 102B and 122. GER:2b

*3 units, Win (Dutton)*

**EE 134. Introduction to Photonics**—Lectures and laboratory experiments on photonics, optical sensors, and fiber optics. Conceptual and mathematical tools for design and analysis of optical communication and sensor systems. Experimental characterization of semiconductor lasers, optical fibers, photodetectors, receiver circuitry, fiber optic links, optical amplifiers, and optical sensors. Prerequisite: EE 141 or equivalent. GER:2b

*4 units, Spr (Solgaard)*

**EE 137. Laboratory Electronics**—(Enroll in APPPHYS 207.)

*3 units, Win (Fox)*

**EE 138. Laboratory Electronics**—(Enroll in APPPHYS 208.)

*3 units, Spr (Fox) alternate years, not given 2005-06*

**EE 140. Introduction to Remote Sensing**—(Enroll in GEOPHYS 140.)

*3 units (Zebker) alternate years, not given 2005-06*

**EE 141. Engineering Electromagnetics**—Lumped versus distributed circuits. Transient response of transmission lines with resistive and reactive loads. Reflection, transmission, attenuation and dispersion. Steady-state waves on transmission lines. Standing wave ratio, impedance matching, and power flow. Coulomb's law, electrostatic field, potential and gradient, electric flux and Gauss's Law and divergence. Metallic conductors, Poisson's and Laplace's equations, capacitance, dielectric materials. Electrostatic energy and forces. Steady electric currents, Ohm's Law, Kirchoff's Laws, charge conservation and the continuity equation, Joule's Law. Biot-Savart's law and the static magnetic field. Ampere's Law and curl. Vector magnetic potential and magnetic dipole. Magnetic materials, forces and torques. Faraday's Law, magnetic energy, displacement current and Maxwell's equations. Uniform plane waves. Prerequisites: 102A, MATH 52. GER:2b

*4 units, Aut (Inan)*

**EE 141M. Engineering Electromagnetics**—Covers approximately the same material as 141 making considerable use of Mathematica. Mathematica allows the smooth integration of algebra, calculus, and graphics. The increased ease of graphics allows, much like a laboratory, better internalization of abstract material. Prerequisite: 102A, MATH 52.

*4 units, Aut (Harris)*

**EE 142. Electromagnetic Waves**—Continuation of 141. Maxwell's equations. Plane waves in lossless and lossy media. Skin effect. Flow of electromagnetic power. Poynting's theorem. Reflection and refraction of waves at planar boundaries. Snell's law and total internal reflection. Reflection and refraction from lossy media. Guided waves. Parallel-plate and dielectric-slab waveguides. Hollow wave-guides, cavity resonators, microstrip waveguides, optical fibers. Interaction of fields with matter and particles. Antennas and radiation of electromagnetic energy. Prerequisite: 141 or PHYSICS 120. GER:2b

*3 units, Win (Inan)*

**EE 144. Wireless Electromagnetic Design Laboratory**—Hands-on experiments and projects with antennas, transmission lines, and propagation for wireless communications and remote sensing. Using spectrum analysers, swept frequency generators, frequency counters, couplers, detectors and slotted lines, develop measurement and design capability in the 1-20 GHz range in support of design projects. 2-3 person team projects. Working model constructed and demonstrated; some funding available. Prizes for best projects. Lab. Enrollment limited to 30. Prerequisite: 122 or 142, or consent of instructor. GER:2b
*3 units, Spr (Leeson)*

**EE 167. Introductory Computer Graphics**—(Enroll in CS 148.)
*3 units, Aut (Johnson)*

**EE 168. Introduction to Digital Image Processing**—Computer processing of digital 2-D and 3-D data, combining theoretical material with implementation of computer algorithms. Topics: properties of digital images, design of display systems and algorithms, time and frequency representations, filters, image formation and enhancement, imaging systems, perspective, morphing, and animation applications. Instructional computer lab exercises implement practical algorithms. Final project consists of computer animations incorporating techniques learned in class. GER:2b
*3-4 units, Win (Zebker)*

**EE 178. Probabilistic Systems Analysis**—Introduction to probability and statistics and their role in modeling and analyzing real world phenomena. Events, sample space, and probability. Discrete random variables, probability mass functions, independence and conditional probability, expectation and conditional expectation. Continuous random variables, probability density functions, independence and expectation, derived densities. Transforms, moments, sums of independent random variables. Simple random processes. Limit theorems. Introduction to statistics: significance, hypothesis testing, estimation and detection, Bayesian analysis. Prerequisites: basic calculus and linear algebra. GER:2b
*3 units, Win (El Gamal)*

**EE 179. Introduction to Communications**—Communication system design and performance analysis. Topics include current communication systems (cellular, WLANs, radio and TV broadcasting, satellites, Internet), Fourier techniques, energy and power spectral density, random variables and random (noise) signals, filtering and modulation of noise, analog modulation (AM and FM) and its performance in noise, digital modulation (PSK and FSK), optimal receiver design, and probability of bit error for digital modulation. Prerequisite: 102A. GER:2b
*3 units, Win (Goldsmith)*

**EE 184. Programming Paradigms**—(Enroll in CS 107.)
*3-5 units, Aut, Spr (Cain)*

**EE 189A. Object-Oriented Systems Design**—(Enroll in CS 108.)
*3-4 units, Win, Spr (Parlante)*

**EE 189B. Software Project**—(Enroll in CS 194.)
*3 units, Win (Young), Spr (Plummer)*

**EE 190. Special Studies or Projects in Electrical Engineering**—Independent work under the direction of a faculty member. Individual or team activities involve lab experimentation, design of devices or systems, or directed reading.
*1-15 units (Staff)*

**EE 191. Special Studies and Reports in Electrical Engineering**—Independent work under the direction of a faculty member given for a letter grade only. If a letter grade given on the basis of required written report or examination is not appropriate, enroll in 190.
*1-15 units (Staff)*

## UNDERGRADUATE AND GRADUATE

**EE 201A. Seminar**—Weekly discussions of topics of current interest in electrical engineering. Orientation to Stanford and to the EE department. Students with a conflict may view via videotape in the library. (AU)
*1 unit, Aut (Reis)*

**EE 201B. Seminar**—Life after Stanford through presentations primarily directed at MS/EE students. The activities of graduates in industry, startups, government laboratories, and community colleges. (AU)
*1 unit, Win (Reis)*

**EE 202. Medical Electronics**—Open to all. Primarily biological in nature, introduction to the physiological and anatomic aspects of medical instrumentation. Areas include patient monitoring, imaging, medical transducers, the unique aspects of medical electronic systems, the socio-economic impact of technology on medical care, and the constraints unique to medicine. Prerequisite: familiarity with circuit instrumentation techniques, such as 101B.
*3 units, Aut (Thompson)*

**EE 203. The Entrepreneurial Engineer**—Seminar furthers the knowledge base of prospective entrepreneurs with an engineering background. The contributions made to the business world by engineering graduates. Speakers include Stanford (and other) engineering and M.B.A. graduates who have founded large and small companies in nearby communities. Contributions from EE faculty and other departments including Law, Business, and MS&E. (AU)
*1 unit, Win (Melen)*

**EE 205. Introduction to Control Design Techniques**—(Enroll in ENGR 205.)
*3 units, Aut (Tomlin)*

**EE 206. Control System Design**—(Enroll in ENGR 206.)
*4 units, Spr (Niemeyer)*

**EE 207D. Optimal Control and Hybrid Systems**—(Enroll in AA 278.)
*3 units, Spr (Tomlin)*

**EE 209A. Analysis and Control of Nonlinear Systems**—(Enroll in ENGR 209A.)
*3 units, Win (Tomlin)*

**EE 209B. Advanced Nonlinear Control**—(Enroll in ENGR 209B.)
*3 units (Tomlin) alternate years, given 2005-06*

**EE 210B. Advanced Topics in Computation for Control**—(Enroll in ENGR 210B.)
*3 units, Aut (Lall)*

**EE 212. Integrated Circuit Fabrication Processes**—For students interested in the physical bases and practical methods of silicon VLSI chip fabrication, or the impact of technology on device and circuit design, or intending to pursue doctoral research involving the use of Stanford's Nanofabrication laboratory. Process simulators are used to illustrate concepts and provide a virtual lab experience. Topics: the fundamental principles of integrated circuit fabrication processes, physical and chemical models for crystal growth, oxidation, ion implantation, etching, deposition, lithography, and back-end processing. Required for 410. Prerequisite: undergraduate semiconductor device physics.
*3 units, Aut (Plummer)*

**EE 213. Heat Transfer in Microdevices**—(Enroll in ME 358.)
*3 units, Spr (Goodson)*

**EE 214. Analog Integrated Circuit Design**—Analysis and design of MOS analog integrated circuits, emphasizing quantitative measures of performance and circuit limitations. Evaluation of circuit performance by means of hand calculations and computer-aided circuit simulations. Design of operational amplifiers and transconductance stages, broadband amplifiers, biasing circuits, and voltage references. Feedback amplifier design. Prerequisite: 101B.
*3 units, Aut (Murmann)*

**EE 215. Bipolar Analog Integrated Circuit Design**—Bipolar analog circuits for high-frequency operation including applications for networking and communications, such as trans-impedance amplifiers (TIA) for optoelectronics and broadband RF amplifiers. Device operation and compact modeling, in support of SPICE simulation needed for design. Circuit building blocks and cascaded stage amplifiers. Analysis and design using feedback circuits. Design projects that meet performance specifications and use SPICE models typical of state-of-the-art bipolar technology.
*3 units, Win (Wooley, Dutton)*

**EE 216. Principles and Models of Semiconductor Devices**—The fundamentals of carrier generation, transport, recombination, and storage in semiconductors. The physical principles of operation of the p-n junction, heterojunction, metal semiconductor contact, bipolar junction transistor, MOS capacitor, MOS and junction field-effect transistors, and related optoelectronic devices such as CCDs, solar cells, LEDs, and detectors. First-order device models that reflect physical principles and are useful for integrated-circuit analysis and design. Prerequisite: 116 or equivalent.
*3 units, Aut (J. Harris), Win (Saraswat, Pease)*

**EE 217. Electron and Ion Beams for Semiconductor Processing**—Focused and flood beams of electrons and ions are employed for processing semiconductor devices. The generation of such beams including thermionic emission, field-induced emission, first-order focusing and glow discharge processes. The interactions of such beams with the target, including scattering in solids, the distribution of energy, heating, sputtering, beam-induced etching (including reactive-ion etching) and beam-induced deposition. Introduction to computer modeling of etching and deposition. Prerequisite: 212.
*3 units (Pease) alternate years, given 2005-06*

**EE 222. Applied Quantum Mechanics I**—Emphasis is on applications in modern devices and systems. Topics include: Schrödinger's equation, eigenfunctions and eigenvalues, operator approach to quantum mechanics, Dirac notation, solutions of simple problems including quantum wells and tunneling. Quantum harmonic oscillator, annihilation and creation operators, coherent states. Two-particle states, entanglement, and Bell states. Quantum key distribution and teleportation. Calculation techniques including matrix diagonalization, perturbation theory, and variational method. Time-dependent perturbation theory, applications to optical absorption, nonlinear optical coefficients, and Fermi's golden rule. Methods for one-dimensional problems: transfer matrix method and WKB method. Quantum mechanics in crystalline materials. Prerequisites: PHYSICS 65 (or PHYSICS 45 and 47) and MATH 43.
*3 units, Aut (Vuckovic)*

**EE 223. Applied Quantum Mechanics II**—Continuation of 222. Angular momentum in quantum mechanics, spin, hydrogen atom, systems of identical particles (bosons and fermions), quantum interference, introductory quantum optics (electromagnetic field quantization, Fock states, coherent states, squeezed states), fermion annihilation and creation operators, interaction of different kinds of particles (spontaneous emission, optical absorption, and stimulated emission). Other topics in electronics, optoelectronics, optics, and quantum information science. Prerequisite: 222.
*3 units, Win (Vuckovic)*

**EE 226. Physics of Quantum Information**—(Enroll in APPPHYS 226.)
*3 units, Win (Yamamoto) alternate years, not given 2005-06*

**EE 227. Applications of Quantum Information**—(Enroll in APPPHYS 227.)
*3 units, Spr (Yamamoto) alternate years, not given 2005-06*

**EE 228. Basic Physics for Solid State Electronics**—Topics: energy band theory of solids, energy bandgap engineering, classical kinetic theory, statistical mechanics, and equilibrium and non-equilibrium semiconductor statistics. Prerequisite: course in modern physics.
*3 units, Aut (Peumans)*

**EE 229B. Thin Film and Interface Microanalysis**—(Enroll in MATSCI 323.)
*3 units, Aut (Brongersma)*

**EE 229D. Introduction to Magnetism and Magnetic Nanostructures**—(Enroll in MATSCI 347.)
*3 units (Wang) not given 2004-05*

**EE 231. Introduction to Lasers**—Introduction to lasers and how they work, including quantum transitions in atoms, stimulated emission and amplification, rate equations, saturation, feedback, coherent optical oscillation, laser resonators, and optical beams. Limited primarily to steady-state behavior; uses classical models for atomic transitions with little quantum mechanics background required. Prerequisites: electromagnetic theory to a level of at least 142, preferably 241, and some knowledge of atomic or modern physics such as PHYSICS 57 or 130-131.
*3 units, Aut (Fejer)*

**EE 232. Laser Dynamics**—Continuation of 231, emphasizing dynamic and transient effects including spiking, Q-switching, mode locking, frequency modulation, frequency and spatial mode competition, linear and nonlinear pulse propagation, short pulse expansion, and compression. Prerequisite: 231.
*3 units, Win (Fejer)*

**EE 234. Photonics Laboratory**—Photonics and fiber optics with a focus on communication and sensing. Experimental characterization of semiconductor lasers, optical fibers, photodetectors, receiver circuitry, fiber optic links, optical amplifiers, and optical sensors. Prerequisite: 142.
*3 units, Aut (Fan)*

**EE 235. Guided Wave Optical Devices**—Guided wave optics, optical waveguide devices, and integrated optics. Wave propagation in layered media, slab waveguides, and optical fibers. Rectangular waveguides. Optical waveguide technology. Coupled-mode theory. Numerical analysis of complex waveguides. Photonic crystals. Physics and design of waveguide devices. Fiber sensors, waveguide gratings, waveguide modulators, directional couplers, ring filters. Prerequisite: electromagnetic theory to the level of 142 or equivalent.
*3 units, Spr (Fan)*

**EE 236. Solid State Physics I**—(Enroll in APPPHYS 272.)
*3 units, Win (Manoharan)*

**EE 237. Solid State Physics II**—(Enroll in APPPHYS 273.)
*3 units, Spr (Manoharan)*

**EE 238. Electronic and Optical Properties of Solids**—(Enroll in MATSCI 199/209.)
*3-4 units, Spr (Brongersma)*

**EE 241. Waves I**—Waves and wave phenomena in natural, lab, and application settings. Electromagnetic, acoustic, seismic, atmospheric, plasma, and water waves and their mathematical and physical correspondence in terms of Hamilton's principle. Propagation, attenuation, reflection, refraction, surface and laminal guiding, and intrinsic and structural dispersion; energy density, power flow, and phase and group velocities. Geometric and structural complexities are minimized to stress basic wave concepts. Analysis in terms of transmission line and impedance concepts using exponential notation and vector phasors. Treatment limited to plane harmonic waves in isotropic media. Nonhomogeneous cases limited to plane interfaces and exponentially stratified media. Prerequisite: 142 or equivalent, or other wave course.
*3 units, Aut (Tyler)*

**EE 243. Semiconductor Optoelectronic Devices**—Operating principles and practical device features. Semiconductor physics and optical processes in semiconductors. Semiconductor heterostructures and optical detectors including p-i-n, avalanche, and MSM, light emitting diodes, electroabsorptive modulators (Franz-Keldysh, QCSE), electrorefractive (directional couplers, Mach-Zehnder), switches (SEEDs), and lasers (waveguide and vertical cavity). Prerequisites: basic quantum mechanics, solid state physics, and lasers, such as 222, 228, 231, or equivalents.
*3 units, Win (J. Harris)*

**EE 244. Communication Engineering Transmission Systems**—Design of transmission systems for TV, telephone, and data-using satellites; microwave repeaters; mobile radio; and broadcast transmitters. Performance of FM, AM, and SSB common digital schemes; TDMA, FDMA, and CDMA; voice, TV and data compression; and error coding. Emphasis is on link performance, capacity, total system design, and cost optimization. Current industry design problems and research results. Examples illustrate modern technologies providing service to rural populations. Project on social and economic factors, and detailed network design for a student-selected rural area. Prerequisite: senior or graduate standing in Electrical Engineering, or consent of instructor.
*3 units, Aut (Lusignan)*

**EE 245. Wireless Electromagnetic Design Laboratory**—Same content as 144 but with a higher level project.
*3 units, Spr (Leeson)*

**EE 246. Microwave Engineering**—Microwave applications (terrestrial and satellite communications, radar, remote sensing, wireless communications) and their system and component requirements. Review of Maxwell's equations. Propagation modes of transmission lines (TEM, waveguide, microstrip), S-parameter matrix modeling of discontinuities, junctions and circuits (impedance transformers, directional couplers, hybrids, filters, circulators, solid state amplifiers and oscillators). Microwave computer-aided design examples. General flow of course is application to system to component; individual components are modeled by fields to modes to equivalent network. Prerequisite: 142.
*3 units (Leeson) not given 2004-05*

**EE 247. Introduction to Optical Fiber Communications**—Fibers: single- and multi-mode, attenuation, modal dispersion, group-velocity dispersion, polarization-mode dispersion. Nonlinear effects in fibers: Raman, Brillouin, Kerr. Self- and cross-phase modulation, four-wave mixing. Sources: light-emitting diodes, laser diodes, transverse and longitudinal mode control, modulation, chirp, linewidth, intensity noise. Modulators: electro-optic, electro-absorption. Photodiodes: p-i-n, avalanche, responsivity, capacitance, transit time. Receivers: high-impedance, transimpedance, bandwidth, noise. Digital intensity modulation formats: non-return-to-zero, return-to-zero. Receiver performance: Q factor, bit-error ratio, sensitivity, quantum limit. Sensitivity degradations: extinction ratio, intensity noise, jitter, dispersion. Wavelength-division multiplexing. System architectures: local-area, access, metropolitan-area, long-haul. Prerequisites: 102A or 261, and 142 or 235 or 241. Corequisite: 278 or 279.
*3 units, Aut (Kahn)*

**EE 248. Fundamentals of Noise Processes**—Mathematical methods and physical principles: statistics, Fourier analysis, statistical and quantum mechanics. Circuit theory: thermal noise, quantum noise, fluctuation-dissipation theorem. Macroscopic and mesoscopic conductors. Macroscopic and mesoscopic pn junctions. 1/f noise and random telegraphic noise. Negative conductance oscillators (lasers) and nonlinear susceptance oscillators (optical parametric amplifier). Optical and quantum communication systems. Weak force detection systems. Prerequisites: elementary device, circuit, and electromagnetic waves to the level of 101A,B and 142.
*3 units, Aut (Yamamoto)*

**EE 249. Introduction to the Space Environment**—The environment through which humankind's space probes and vehicles travel and orbit and which moderates the gases and radiation from the Sun. Experimentation, tools used, and the regions into which it is divided including the ionosphere, the magnetosphere, and interplanetary space. The role of the Sun, the effects of changes in solar activity, charged particle motion which in combination with the earth's magnetic field leads to auroras and the Van Allen belts. Prerequisites: electromagnetics at the level of 142, and senior or graduate standing.
*3 units (Fraser-Smith) alternate years, given 2005-06*

**EE 251. Progress in Worldwide Telecommunications**—(Enroll in MS&E 237.)
*3 units, Sum (Ivanek, Chiu)*

**EE 252. Antennas for Telecommunications and Remote Sensing**—Fundamental parameters. Dipoles, loops, reflectors, Yagis, helices, slots, horns, micro-strips. Antennas as transitions between guided and free radiation, ultrasound analogue. Famous antennas. Pattern measurements. Friis and radar equations. Feeds, matching, baluns. Broadbanding. Arrays, aperture synthesis, interferometry, very-long-baseline interferometry. Thermal radiation, antenna temperature, microwave passive remote sensing. Prerequisite: 142 or equivalent.
*3 units, Spr (Tyler) alternate years, not given 2005-06*

**EE 254. Principles of Radar Systems**—Analysis and design, emphasizing radars as systems. Radar equation and systems parameters, components of radar systems, radar cross-section and target characteristics, signal detection in noise, ambiguity function (with applications to measurement precision, resolution, clutter rejection, and waveform design); pulse compression waveforms, synthetic aperture radar, tracking and scanning radars, HF (OTH) radar, radar environmental and remote sensing, radar astronomy. Prerequisite: senior undergraduate or graduate standing.
*3 units (Zebker, Tyler) alternate years, given 2005-06*

**EE 256. Numerical Electromagnetics**—The principles and applications of numerical techniques for solving practical electromagnetics problems. Time domain solutions of Maxwell's equations. Finite Difference Time Domain (FDTD) methods. Numerical stability, dispersion, and dissipation. Step and pulse response of lossy transmission lines and interconnects. Absorbing boundary conditions. FDTD modeling of propagation and scattering in dispersive media. Near-to-far-zone transformations. Moment method solutions of integral equations, with applications to antenna problems. Computational problems require programming and use of MATLAB and other tools. Prerequisite: 142 or equivalent.
*3 units, Spr (Inan) alternate years, not given 2005-06*

**EE 261. The Fourier Transform and its Applications**—The Fourier transform as a tool for solving physical problems. Fourier series, the Fourier transform of continuous and discrete signals and its properties. The Dirac delta, distributions, and generalized transforms. Convolutions and correlations and applications; probability distributions, sampling theory, filters, and analysis of linear systems. The discrete Fourier transform and the FFT algorithm. Multidimensional Fourier transform and use in imaging. Further applications to optics, crystalography. Emphasis is on relating the theoretical principles to solving practical engineering and science problems. Prerequisites: exposure to Fourier series at the level of 102A, and linear algebra.
*3 units, Aut (Osgood), Win (Hesselink)*

**EE 262. Two-Dimensional Imaging**—Time and frequency representations, two-dimensional auto- and cross-correlation, Fourier spectra, diffraction and antennas, coordinate systems and the Hankel and Abel transforms, line integrals, impulses and sampling, restoration in the presence of noise, reconstruction and tomography, imaging radar. Tomographic reconstruction using projection-slice and layergarm methods. Students create software to form images using these techniques with actual data. Final project consists of design and simulation of an advanced imaging system. Prerequisite: 261. Recommended: 278, 279.
*3 units, Spr (Zebker) alternate years, not given 2005-06*

**EE 263. Introduction to Linear Dynamical Systems**—Introduction to applied linear algebra and linear dynamical systems with application to circuits, signal processing, communications, and control systems. Topics: least-squares approximations of over-determined equations and least-norm solutions of underdetermined equations. Symmetric matrices, matrix norm, and singular value decomposition. Eigenvalues, left and right eigenvectors, with dynamical interpretation. Matrix exponential, stability, and asymptotic behavior. Multi-input/multi-output systems, impulse and step matrices; convolution and transfer matrix descriptions. Control, reachability, and state transfer. Least-norm inputs and associated Gramians. Prerequisites: basic linear algebra and matrices (as in MATH103); differential equations and Laplace transforms (as in 102A).
*3 units, Aut (Boyd)*

**EE 264. Digital Filtering**—Introduction to digital signal processing techniques. Two sided Z-transform. SISO and MIMO flowgraphs, Markov graphs. Discrete-time Wiener filtering. Laplace transform, mixed discrete and continuous feedback systems. Interpolation techniques for D/A conversion. Discrete Fourier transform and its applications. Finite impulse response (FIR) and infinite impulse response (IIR) filter designs. Theory of quantization noise. Prerequisite: 102B. Recommended: 261, 278.
*3 units, Aut (Widrow)*

**EE 265. Signal Processing Laboratory**—Applying 102A,B to real-world signal processing applications. Lab exercises use a programmable DSP to implement signal processing tasks. Topics: A/D conversion and quantization, sampling theorem, Z-transform, discrete-time Fourier transform, IIR filters, FIR filters, filter design and implementation, spectral analysis, rate conversion, wireless data communication. Prerequisite: 102A,B. Recommended: 261.
*3-4 units, Aut, Win (Meng)*

**EE 268. Introduction to Modern Optics**—Geometrical optics: ray matrices, Gaussian beams, optical instruments, and radiometry. Wave nature of light: Maxwell's equations, propagation through media with varying index of refraction (e.g., fibers). Interferometry: basic principles, practical systems, and applications. GER:2a
*3 units, Aut (Byer) alternate years, not given 2005-06*

**EE 271. Introduction to VLSI Systems**—Large-scale MOS design. Topics: MOS transistors, static and dynamic MOS gates, MOS circuit fabrication, design rules, resistance and capacitance extraction, power and delay estimation, scaling, MOS combinational and sequential logic design, registers and clocking schemes, memory, data-path, and control-unit design. Elements of computer-aided circuit analysis, synthesis, and layout techniques. Prerequisites: 101A and 108B; familiarity with circuits, logic design, and digital system organization.
*3 units, Aut (DiMicheli)*

**EE 273. Digital Systems Engineering**—Fundamental electrical issues in the design of high-performance digital systems, including signaling, timing, synchronization, noise, and power distribution. High-speed signaling methods; noise in digital systems, its affect on signaling, and methods for noise reduction; timing conventions; timing noise (skew and jitter), its affect on systems, and methods for mitigating timing noise; synchronization issues and synchronizer design; clock and power distribution problems and techniques; impact of electrical issues on system architecture and design. Prerequisites: 108A and 102B, or equivalents.
*3 units, Win (Blennemann)*

**EE 274. Introduction to Cryptography**—(Enroll in CS 255.)
*3 units, Win (Boneh)*

**EE 275. Logic Design**—Principles and techniques of logic design. Combinational circuit analysis (hazard detection); combinational circuit design including PLA, VLSI, and MSI techniques and testing techniques; IC logic, flipflop properties, sequential circuit analysis and synthesis for fundamental and pulse mode circuits, design for testability techniques. Prerequisite: 121 or equivalent.
*3 units, Aut (Al-Yamani)*

**EE 276. Introduction to Wireless Personal Communications**—Frequency reuse, cellular concepts, cochannel interference, handoff. Radio propagation in and around buildings: Friis equation, multipath, narrowband and wide-band channels, small scale and large-scale statistics, space and time signal variation. Diversity. Receiver sensitivity, sources of noise, range. Performance statistics: coverage, margin, digital modulation, adjacent channel interference, and digital error rates. Wide band channels: maximum transmission rates. Multi-server queuing and traffic: Erlang formulas. Prerequisites: 142 and 278 or equivalent. Corequisite: 279 or equivalent.
*3 units (Cox) not given 2004-05*

**EE 277. Stochastic Decision Models**—(Enroll in MS&E 251.)
*3 units, Win (Veinott)*

**EE 278. Introduction to Statistical Signal Processing**—Random variables, vectors, and processes; convergence and limit theorems; IID, independent increment, Markov, and Gaussian random processes; stationary random processes; autocorrelation and power spectral density; mean square error estimation, detection, and linear estimation. Prerequisites: 178 or STATS 116, and linear systems and Fourier transforms at the level of 102A,B or 261.
*3 units, Aut (El Gamal), Spr (Gill)*

**EE 279. Introduction to Communication Systems**—Analysis and design; analog and digital modulation and demodulation, frequency conversion, multiplexing, noise, and distortion; spectral and signal-to-noise ratio analysis, probability of error in digital systems, spread spectrum. Prerequisites: 179 or 261, and 178 or 278.
*3 units, Win (Hashemi)*

**EE 281. Embedded System Design Laboratory**—Architecture and design of microprocessor-based systems. Lab experiments use Atmel AVR microcontroller evaluation boards. Five-week individual design project. Lab. Prerequisites: 108A and 108B or equivalent experience in assembly language programming.
*3 units (Staff) alternate years, given 2005-06*

**EE 282. Computer Architecture and Organization**—Advanced topics in cache hierarchies, memory systems, storage and IO systems, interconnection networks, and message-passing multiprocessor systems (clusters). Issues such as locality, coarse-grain parallelism, synchronization, overlapping communication with computation, hardware/software interfaces, performance/power trade-offs, reliability. Characteristics of modern processors that affect system architecture. Prerequisite: 108B.
*3 units, Aut (Kozyrakis)*

**EE 283. Compilers**—(Enroll in CS 143.)
*3-4 units, Aut (Aiken), Spr (Johnson)*

**EE 284. Introduction to Computer Networks**—Structure and components of computer networks; functions and services; packet switching; layered architectures; OSI reference model; physical layer; data link layer; error control; window flow control; media access control protocols used in local area networks (Ethernet, Token Ring, FDDI) and satellite networks; network layer (datagram service, virtual circuit service, routing, congestion control, Internet Protocol); transport layer (UDP, TCP); application layer.
*3-4 units, Aut (Tobagi)*

**EE 284A. Introduction to Computer Networks**—(Enroll in CS 244A.)
*3-4 units, Win (McKeown)*

**EE 285. Programming Languages**—(Enroll in CS 242.)
*3 units, Aut (Mitchell)*

**EE 286A. Operating Systems and Systems Programming**—(Enroll in CS 140.)
*3-4 units, Aut, Win (Rosenblum)*

**EE 286B. Advanced Topics in Operating Systems**—(Enroll in CS 240.)
*3 units, Win, Spr (Engler)*

**EE 287. Introduction to Computer Graphics**—(Enroll in CS 248.)
*3-5 units, Aut (Levoy)*

**EE 288. Mathematical Methods for Robotics, Vision, and Graphics**—(Enroll in CS 205.)
*3 units, Aut (Fedkiw)*

**EE 289. Introduction to Computer Vision**—(Enroll in CS 223B.)
*3 units, Win (Thrun)*

**EE 290A,B,C. Curricular Practical Training for Electrical Engineers**—For EE majors who need relevant work experience as part of their program of study. Final report required. Prerequisite for 290B: candidate for Engineer or Ph.D. in Electrical Engineering. Prerequisite for 290C: candidate for Ph.D. degree in Electrical Engineering.
*1 unit, Aut, Win, Spr, Sum (Gray)*

**EE 292. Special Seminars**

**EE 292A. Global Positioning Systems**—(Enroll in AA 272C.)
*3 units, Win (Enge)*

**EE 292B. Electronic Documents: Paper to Digital**—Core technologies that underlie and enable the transformation of paper documents and document collections to digital form. Scanner technology and digital camera hardware, document image analysis including optical character recognition (OCR), textual information retrieval, document representation technologies including structured and hypertext document standards, image and text compression, electronic book (eBook) engineering, digital rights management technologies, data encryption and security, knowledge management, and user interface design. Emphasis is on basic technological principles. Guest lectures from PARC innovators. Term project. Prerequisites: basic probability and linear algebra, programming skills. Recommended: 102B or 168.
*3 units, Spr (Popat)*

**EE 292E. Analysis and Control of Markov Chains**—Finite-state and countable-state Markov chains. Controlled Markov chains and dynamic programming algorithms. Application to modeling and analysis of engineering systems. Prerequisites: 263, 278.
*3 units, Win (Van Roy)*

**EE 293A. Fundamentals of Energy Processes**—For seniors and graduate students. Theory of modern energy conversion, transmission, and storage methods. Windmills. Heat engines: classical engines, ocean thermal energy converters, thermoelectric, thermoionic, and radio-noise engines. Prerequisites: PHYSICS 55 and MATH 43.
*3-4 units, Aut (da Rosa)*

**EE 293B. Fundamentals of Energy Processes**—For seniors and graduate students. Fuel cells. Production of hydrogen: electrolytic, chemical, thermolytic, photolytic. Hydrogen storage: hydrides. Insolation. Photoelectric converters; photo-thermovoltaic converters. Biomass: photosynthesis, production of methane and ethanol from vegetable matter. Prerequisites: PHYSICS 55 and MATH 43, or equivalent.
*3-4 units, Win (da Rosa)*

**EE 294A. Artificial Intelligence: Principles and Techniques**—(Enroll in CS 221.)
*3-4 units, Aut (Ng)*

**EE 294B. Probabilistic Models in Artificial Intelligence**—(Enroll in CS 228.)
*3 units, Aut (Koller)*

**EE 294C. Machine Learning**—(Enroll in CS 229.)
*3 units, Aut (Ng)*

**EE 294X. Modern Applied Statistics: Elements of Statistical Learning I**—(Enroll in STATS 315A.)
*2-3 units, Win (Tibshirani)*

**EE 294Y. Modern Applied Statistics: Elements of Statistical Learning II**—(Enroll in STATS 315B.)
*2-3 units, Spr (Friedman)*

## GRADUATE

**EE 300. Master's Thesis and Thesis Research**—For students who wish to do independent work under the direction of a department faculty member as part of their master's degree program. Written thesis required for final letter grade. The continuing grade 'N' is given in quarters prior to thesis submission. See 390 if a letter grade is not appropriate.
*1-15 units (Staff)*

**EE 310. Integrated Circuits Technology and Design Seminar**—Current research topics in device structures, fabrication technologies, and circuit design issues in integrated circuits.
*1 unit, Aut (Wooley)*

**EE 311. Advanced Integrated Circuit Fabrication Processes**—Practical and fundamental limits to the evolution of the technology of modern MOS and bipolar devices. Modern device and circuit fabrication and likely future changes. Advanced techniques and models of device and back-end (interconnect and contact) processing. Use of TSUPREM4 and PISCES for process and device modeling. MOS and bipolar process integration. Prerequisites: 212, 216.
*3 units, Spr (Saraswat)*

**EE 312. Micromachined Sensors and Actuators**—Solid-state sensors and actuators, focusing on the use of integrated circuit fabrication technology for their realization. Categories of sensors and actuators include biological, chemical, mechanical, optical, and thermal. Basic mechanisms of transduction, fabrication techniques, and the relative merits of different technologies. Micromachining techniques for monolithic integration of active circuits with sensors or actuators and directions for future research. Prerequisite: 212 or equivalent.
*3 units (Kovacs) not given 2004-05*

**EE 313. Digital MOS Integrated Circuits**—Analysis and design of digital MOS integrated circuits. Development of different models for MOS transistors and how to use them to analyze circuit performance. Use of computer-aided circuit analysis. Logic styles include static, dynamic and pass logic, pulse-mode gates, and current-mode logic. Topics include sizing for min delay, noise and noise margins, power dissipation. Memory design (SRAM) as a motivating example. DRAM and EEPROM design issues. Prerequisites: 101B, 108A. Recommended: 271.
*3 units, Win (Staff)*

**EE 314. RF Integrated Circuit Design**—Design of RF integrated circuits for communications systems, primarily in CMOS. Topics: the design of matching networks and low-noise amplifiers at RF, passive and active filters, mixers, modulators, and demodulators; review of classical control concepts necessary for oscillator design including PLLs and PLL-based frequency synthesizers. Design of low phase noise oscillators. Design of high-efficiency (e.g., class E, F) RF power amplifiers, coupling networks. Behavior and modeling of passive and active components at RF. Narrowband and broadband amplifiers; noise and distortion measures and mitigation methods. Overview of transceiver architectures. Prerequisite: 214.
*3 units, Win (Lee)*

**EE 315. VLSI Data Conversion Circuits**—Design of mixed-signal integrated circuits for implementing the interfaces between analog and digital signals in CMOS VLSI systems. Fundamental circuit elements such as sample-and-hold circuits, comparators, voltage references, operational amplifiers, gain blocks, and analog integrators. The design of the constituent circuits for Nyquist-rate and oversampling analog-to-digital and digital-to-analog converters, sampled-data and continuous-time analog filters, and digital decimation and interpolation filters. Prerequisite: 214.
*3 units, Spr (Murmann)*

**EE 316. Advanced VLSI Devices**—In modern VLSI technologies, MOS and bipolar device electrical characteristics are sensitive to structural details and therefore to fabrication techniques. How are advanced VLSI devices designed and what future changes are likely? What are the implications for device electrical performance caused by fabrication techniques? Physical models for submicron structures, control of electrical characteristics (threshold voltage, breakdown voltage, current gain) in small structures, and alternative device structures for VLSI. Prerequisites: 212, 216, or equivalent.
*3 units, Win (Wong)*

**EE 317. Micropatterning for Integrated Circuits**—The fundamentals of generating submicron patterns in integrated circuit manufacturing. Technologies include the formation of submicron images of ultraviolet light, the resulting exposure of polymeric resists, the subsequent development of resist patterns and their transfer into functional circuit material patterns through plasma etching and other techniques. The use of phase-shifting masks and other wavefront-engineering approaches. Extensive hands-on use of computer simulations of each of the above steps. Prerequisites: 141 or equivalent, 212 or equivalent, basic competence in computing.
*3 units, Spr (Pease) alternate years, not given 2005-06*

**EE 318. Logic Synthesis of VLSI Circuits**—Solving logic design problems with CAD tools for VLSI circuits. Analysis and design of exact and heuristic algorithms for logic synthesis. Topics: representation and optimization of combinational logic functions (encoding problems, binary decision diagrams), representation and optimization of multiple-level networks (algebraic and Boolean methods, don't-care set computation, timing verification, and optimization), modeling and optimization of sequential functions and networks (retiming), semicustom libraries and library binding. Prerequisites: familiarity with logic design, algorithm development, and programming.
*3 units, Win (DeMicheli)*

**EE 319. Computer-Aided System Design Laboratory**—Computer-aided design of VLSI systems: theory and practice. Topics: modeling languages (e.g., Verilog), high-level synthesis and optimization methods (scheduling, binding, data-path, and control synthesis), design of systems with low power consumption, and hardware/software co-design. Individual/group projects involve the use of CAD tools. Prerequisite: 318.
*3 units, Spr (DeMicheli)*

**EE 320. Automatic Formal Verification Techniques**—(Enroll in CS 356.)
*3 units, Spr (Dill)*

**EE 321. MEMS Design**—Theory and practice of MEMS design. Micromechanical fundamentals and CAD tools for definition, design and layout of MEMS. Case studies of successful MEMS engineering projects. Emphasis is on physical understanding and elementary modeling, not numerical simulations. Students complete a MEMS design project which includes layout, evaluation strategy, and modeling. Prerequisite: 312 or equivalent.
*3 units, Aut (Solgaard) alternate years, not given 2005-06*

**EE 322. Molecular Electronics and Photonics**—Physics of charge and energy transfer in molecular systems and connection with traditional mesoscopic transport theories. Analysis of molecular organic light-emitting diodes, photovoltaic cells and transistors. Technology and applications of molecular semiconductors. Prerequisite: 228 or equivalent.
*3 units, Win (Peumans)*

**EE 325. Nanoscale Science, Engineering, and Technology**—(Enroll in MATSCI 316.)
*3 units Win (McGehee)*

**EE 326. Organic Semiconductors for Electronics and Photonics**—(Enroll in MATSCI 343.)
*3 units, Spr (McGehee)*

**EE 327. Properties of Semiconductor Materials**—Modern semiconductor devices and integrated circuits are based on the unique energy band, carrier transport, and optical properties of semiconductor materials. These physical properties can be chosen and optimized for operation of semiconductor devices. Emphasis is on the quantum mechanical foundations of the properties of solids, energy bandgap engineering, semi-classical transport theory, semiconductor statistics, carrier scattering, electro-magneto transport effects, high field ballistic transport, Boltzmann transport equation, quantum mechanical transitions, optical absorption, and radiative and non-radiative recombination. Prerequisites: 216, 228.
*3 units, Spr (J. Harris) alternate years, not given 2005-06*

**EE 328. Physics of Advanced Semiconductor Devices**—Principles governing the operation of modern semiconductor devices. Assumptions and approximations commonly made in analyzing devices. Emphasis is on the application of semiconductor physics to the development of advanced semiconductor devices (e.g., heterojunctions, HJ-bipolar transistors, HJ-FETs, nano structures, tunneling, single electron transistor and photonic devices). Training in and use of ATLAS, a 2-D Poisson solver, for simulation of ultra-small devices. Examples are related to state-of-the-art devices and current device research. Prerequisite: 216.
*3 units (J. Harris) alternate years, given 2005-06*

**EE 329. The Electronic Structure of Surfaces and Interfaces**—Physical concepts and phenomena for surface science techniques probing the electronic structure of surfaces and interfaces. Microscopic and atomic models in understanding microstructures have technologically important applications such as within semiconductor device technology and catalysis. Physical processes of low energy electron diffraction, Auger electron spectroscopy, UV and x-ray photoemission spectroscopy, electron/photon stimulated ion desorption, inelastic tunneling spectroscopy, ion scattering, surface EXAFS, and energy loss spectroscopy; and experimental aspects of these surface science techniques. Prerequisites: PHYSICS 70, 238; or consent of instructor.
*3 units, Aut (Pianetta) alternate years, not given 2005-06*

**EE 335. Introduction to Information Storage Systems**—Data storage technologies including optical data storage (CD-ROM, DVD, magneto-optic recording, and holographic recording), solid state memory (flash memory, ferroelectric memory, and emerging magnetic random access memory), probe-based storage, and magnetic disk drives. Comparisons among data storage technologies. Related nanotechnologies. Prerequisites: electromagnetism, optics, transistors, binary algebra, probability, and Fourier transform.
*3 units, Win (Richter)*

**EE 336. Nanophotonics**—(Same as MATSCI 346.) Recent developments in micro- and nanophotonic materials and devices. Basic concepts of photonic crystals. Integrated photonic circuits. Photonic crystal fibers. Superprism effects. Optical properties of metallic nanostructures. Sub-wavelength phenomena and plasmonic excitations. Meta-materials.
*3 units, Win (Fan, Brongersma)*

**EE 338A. Quantum Optics and Measurements**—(Enroll in APPPHYS 387.)
*3 units (Yamamoto) alternate years, given 2005-06*

**EE 338B. Mesoscopic Physics and Nanostructures**—(Enroll in APPPHYS 388.)
*3 units (Yamamoto) alternate years, given 2005-06*

**EE 340. Advanced Topics in Optics and Quantum Optics**—This year's topic is optical microcavities and their device applications. Types of optical microcavities (microdisks, microspheres, and photonic crystal cavities), and their electromagnetic properties, design, and fabrication techniques. Cavity quantum electrodynamics: strong and weak-coupling regime, Purcell factor, spontaneous emission control. Applications of optical microcavities, including low-threshold lasers, resonant cavity light-emitting diodes, and single-photon sources. Prerequisites: advanced undergraduate or basic graduate level knowledge of electromagnetics, quantum mechanics, and physics of semiconductors.
*3 units, Spr (Vuckovic)*

**EE 343. Advanced Optoelectronic Devices**—Semiconductor quantum well structures; superlattices and coupled quantum wells; optical properties of quantum wells; valence band structure; effects of strain; quantum well lasers; intersubband detectors; excitons in quantum wells; absorption saturation; electroabsorption; quantum well modulators and switches. Prerequisites: 222 or equivalent quantum mechanics, 243.
*3 units (Miller) alternate years, given 2005-06*

**EE 344. High Frequency Laboratory**—Combination lecture/lab emphasizing the lab. Techniques in the 1MHz-1GHz range useful in designing and measuring oscillators, amplifiers, and mixers. Basic high frequency measurement techniques including s-parameter measurements, Amplifier Noise Figure; and oscillator phase noise. Lectures by the professor and experts from Lucent and Hewlett-Packard. (Two lectures, one lab weekly.) Enrollment limited to 20. Prerequisites: good understanding of transmission lines, Smith charts.
*3 units, Aut (Cox)*

**EE 346. Introduction to Nonlinear Optics**—Wave propagation in anisotropic, non-linear, and time-varying media. Microscopic and macroscopic description of electric dipole susceptibilities. Free and forced waves-phasematching; slowly varying envelope approximation-dispersion, diffraction, space-time analogy; harmonic generation; frequency conversion; parametric amplification and oscillation; electro-optic light modulation; nonlinear processes in optical fibers. Prerequisites: 141, 142.
*3 units, Spr (S. Harris)*

**EE 347. Optical Methods in Engineering Science**—The design and understanding of modern optical systems. Topics: geometrical optics; aberration theory; systems layout; applications such as microscopes, telescopes, optical processors. Computer ray tracing program is used for demonstrations and as a design tool. Prerequisite: 268 or 366, or equivalent.
*3 units (Hesselink) alternate years, given 2005-06*

**EE 348. Advanced Optical Fiber Communications**—Optical amplifiers: gain, saturation, noise. Semiconductor amplifiers. Erbium-doped fiber amplifiers. System applications: preamplified receiver performance, amplifier chains. Raman amplifiers, lumped vs. distributed amplification. Group-velocity dispersion management: dispersion-compensating fibers, filters, gratings. Interaction of dispersion and nonlinearity, dispersion maps. Multichannel systems. Wavelength-division multiplexing components: filters, multiplexers. WDM systems, crosstalk. Time-, subcarrier-, code- and polarization-division multiplexing. Solitons, loss- and dispersion-managed solitons. Comparison of modulation techniques: duobinary, pulse-amplitude modulation, differential phase-shift keying, phase-shift keying, quadrature-amplitude modulation. Comparison of detection techniques: noncoherent, differentially coherent, coherent. Spectral efficiency limits. Error-control coding. Prerequisite: 247.
*3 units, Win (Kahn)*

**EE 349. Nano Optics and Grating Photonics**—Coupled wave analysis of periodic structures, gratings structures for optical communcations, wave-matter interactions with periodic media and photonic crystals, applications of periodic structures. Prerequisites: 268 or 366, or equivalent.
*3 units (Hesselink) alternate years, given 2005-06*

**EE 350. Radioscience Seminar**—Seminars by university and industrial researchers on topics from space physics, planetary exploration, ionospheric and magnetospheric physics, radar and remote sensing of the environment, applied electromagnetics, waves in optical fibers, and information systems with space applications. Student-faculty discussions.
*1 unit, Aut (Tyler), Win (Inan)*

**EE 352. Electromagnetic Waves in the Ionosphere and Magnetosphere**—Magneto-ionic theory in multi-component media, signal dispersion, group ray velocity, wave polarization, refractive index surfaces, ray tracing, absorption, boundary effects, interpretation of natural phenomena (whistlers, VLF emissions), remote sensing in plasmas, communication, theory of wave-particle interactions in the magnetosphere. Prerequisite: 142 or equivalent.
*3 units (Helliwell) alternate years, given 2005-06*

**EE 354. Introduction to Radio Wave Scattering**—Integral and differential equations of radio wave scattering; exact, approximate, and numerical solutions of single particle scattering for spheres, edges, points, and cylinders. Scattering from rough surfaces with large and small roughness scales, as time permits. Multiple scattering; formulation and solution techniques for equation of transfer in discrete media and scattering by continuous media in weak and strong regimes. Applications to radar, radar astronomy, remote sensing, and biological media. Prerequisites: electromagnetic theory through standard graduate engineering topics. Partial differential equations, boundary value problems in rectangular and spherical coordinates. Consent of instructor.
*3 units, Win (Tyler) alternate years, not given 2005-06*

**EE 355. Radar Remote Sensing: Fundamentals and Geophysical Application of Imaging Radar Systems**—(Enroll in GEOPHYS 265.)
*3 units (Zebker) alternate years, given 2005-06*

**EE 356. Elementary Plasma Physics: Principles and Applications**—Plasmas in nature and industry. Basic plasma characteristics. Single particle motions. Plasma kinetic theory. The Boltzmann equation and its moments. Cold and warm plasma models. Plasma as a fluid. Magnetohydrodynamics. Plasma conductivity and diffusion. Langmuir oscillations. Debye shielding. Plasma sheath. Waves in cold plasmas. Waves in magnetized, warm, and hot plasmas. Electron and ion waves. MHD waves. Landau damping. Nonlinear effects. Applications in industry and space science. Prerequisite: 142 or PHYSICS 122.
*3 units (Inan) not given 2004-05*

**EE 358A. Lasers Laboratory**—(Enroll in APPPHYS 304.)
*3 units, Win (Byer)*

**EE 358B. Nonlinear Optics Laboratory**—(Enroll in APPPHYS 305.)
*3 units (Byer) alternate years, given 2005-06*

**EE 359. Wireless Communication**—Design, performance analysis, and fundamental performance limits. Topics include: current wireless systems, path loss and shadowing, statistical multipath channel models, capacity of wireless channels, digital modulation and its performance in fading and intersymbol interference, adaptive modulation, diversity, multiple antenna systems (MIMO), equalization, multicarrier modulation, and spread spectrum and RAKE receivers. Multiuser system design issues such as multiple access, frequency reuse in cellular systems, and ad hoc wireless network design. Prerequisites: 279.
*3 units, Aut (Goldsmith)*

**EE 360. Wireless Networks**—Multiuser wireless systems and networks. Possible topics include multiuser detection and interference cancellation, cellular system design and optimization, dynamic resource allocation and power control, handoff and mobility management, access and channel assignment, wireless network routing, Shannon capacity and achievable rate regions of wireless networks, ad hoc wireless network design, sensor and energy-constrained networks, QoS support, and joint network and application design. Topics covered determined at the beginning of the quarter with student input.
*3 units (Goldsmith) alternate years, given 2005-06*

**EE 361A. Modern Control Design I**—(Enroll in ENGR 207A.)
*3 units, Win (Lall)*

**EE 361B. Modern Control Design II**—(Enroll in ENGR 207B.)
*3 units, Spr (Lall)*

**EE 362. Applied Vision and Image Systems**—(Enroll in PSYCH 221.)
*1-3 units (Wandell) not given 2004-05*

**EE 363. Linear Dynamic Systems**—Continuation of 263. Optimal control and dynamic programming; linear quadratic regulator. Lyapunov theory and methods. Linear estimation and the Kalman filter. Perron-Frobenius theory. Examples and applications from digital filters, circuits, signal processing, and control systems. Prerequisite: 263 or equivalent; basic probability.
*3 units (Boyd) alternate years, given 2005-06*

**EE 364. Convex Optimization with Engineering Applications**—Convex sets, functions, and optimization problems. The basics of convex analysis and theory of convex programming: optimality conditions, duality theory, theorems of alternative, and applications. Least-squares, linear and quadratic programs, semidefinite programming, and geometric programming. Numerical algorithms for smooth unconstrained problems; interior-point and ellipsoid methods for constrained problems. Applications to signal processing, communications, control, analog and digital circuit design, computational geometry, statistics, and mechanical engineering. Prerequisites: linear algebra such as 263, background in applications, and willingness to program in Matlab.
*3 units, Spr (Boyd) alternate years, not given 2005-06*

**EE 366. Introduction to Fourier Optics**—Applications of Fourier theory to the analysis and synthesis of optical imaging and optical data processing systems. Propagation and diffraction of light, Fresnel and Fraunhofer approximations, Fourier transforming properties of lenses, image formation with coherent and incoherent light, transform functions of imaging systems, optical data processing, and holography. Prerequisite: familiarity with Fourier analysis. Recommended: 261.
*3 units, Aut (Hesselink) alternate years, not given 2005-06*

**EE 367A. Signal Processing Methods in Musical Acoustics**—(Enroll in MUSIC 420.)
*3-4 units, Win (J. Smith)*

**EE 367B. Audio Applications of the Fast Fourier Transform (FFT)**—(Enroll in MUSIC 421.)
*3-4 units, Spr (J. Smith)*

**EE 367C. Perceptual Audio Coding**—(Enroll in MUSIC 422.)
*3 units, Win (Bosi)*

**EE 368. Digital Image Processing**—Image sampling and quantization, point operations, linear image filtering and correlation, image transforms, eigenimages, multidimensional signals and systems, multiresolution image processing, wavelets, morphological image processing, noise reduction and restoration, simple feature extraction and recognition tasks, image registration. Emphasis is on the general principles of image processing. Students write and investigate image processing algorithms in Matlab. Competitive term project. Prerequisites: 261, 278.
*3 units (Girod) not given 2004-05*

**EE 369A. Medical Imaging Systems I**—Imaging internal structures within the body using high-energy radiation studied from a systems viewpoint. Modalities covered: x-ray, computed tomography, and nuclear medicine. Analysis of existing and proposed systems in terms of resolution, frequency response, detection sensitivity, noise, and potential for improved diagnosis. Prerequisite: 261.
*3 units, Win (Nishimura)*

**EE 369B. Medical Imaging Systems II**—Imaging internal structures within the body using non-ionizing radiation studied from a systems viewpoint. Modalities include ultrasound and magnetic resonance. Analysis of ultrasonic systems including diffraction and noise. Analysis of magnetic resonance systems including physics, Fourier properties of image formation, and noise. Prerequisite: 261.
*3 units, Spr (Pauly)*

**EE 369C. Medical Image Reconstruction**—Reconstruction from non-uniform frequency domain data, automatic deblurring, phase unwrapping, reconstruction from incomplete data. Examples drawn from fast magnetic resonance imaging methods including spiral, echo-planar, multi-coil/parallel and partial k-space reconstructions. Prerequisite: 369B.
*3 units (Pauly) not given 2004-05*

**EE 371. Advanced VLSI Circuit Design**—Issues in high performance digital CMOS VLSI design from a system perspective. Topics: wire modeling, logic families, latch design and clocking issues, clock distribution, RAMs, ALUs, I/O and I/O noise issues. Final project involves the design of a subsystem for a high-speed processor. Extensive use of SPICE. Prerequisites: 271 and 313, or consent of instructor.
*3 units, Spr (Staff)*

**EE 372. Quantization and Compression**—Theory and design of codes for quantization and signal compression systems (source coding systems), systems which convert analog or high bit rate digital signals into low bit rate digital signals while optimizing fidelity subject to available communication or storage capacity. Applications to the design of systems for compression, statistical classification, and density estimation using statistical clustering techniques. Asymptotic theory: Zador/Gersho theory for high rate quantization theory and Shannon rate-distortion theory. Code structures: uniform and lattice codes, tree structured codes, transform codes, composite codes, universal codes. Mismatch and dithering. Prerequisites: 261, 278. Recommended: 376A, MATH 137.
*3 units (Gray) alternate years, given 2005-06*

**EE 373A. Adaptive Signal Processing**—Self-optimizing systems whose performance is improved through contact with their environments. Feedback models for least mean-square adaptation processes. Steepest descent, Newton's method, and Southwell relaxation methods. Random search. LMS algorithm. Efficiency measures for adaptive processes. Adaptive digital filters, noise canceling and signal enhancement, adaptive antennas, adaptive control systems. Original theoretical and experimental research projects in electrical engineering and biomedical engineering, teamwork. Prerequisites: 263, 264. Recommended: 278.
*3 units, Win (Widrow)*

**EE 373B. Adaptive Neural Networks**—Adaptive threshold elements, Feedforward layered networks, Back propagation algorithm. Optimal decision making. Learning by punish/reward. Adaptive gaming. Experimental and theoretical applications of neural networks to pattern recognition, speech recognition, and self-learning adaptive control systems. Nonlinear adaptive filtering. Volterra adaptive filtering. Self-organizing maps. Support vector machines. Radial basis functions. Recurrent neural networks. Original theoretical and experimental research projects in electrical engineering and biomedical engineering, teamwork. Continuation of projects begun in 373A. Prerequisite: 373A.
*3 units, Spr (Widrow)*

**EE 376A. Information Theory**—Information theory and statistics. The extreme points of communication theory: data compression to the entropy limit, and communication at the channel capacity limit. Kolmogorov complexity, Shannon entropy. Rate distortion theory. Huffman coding and random coding. Unified treatment based on the asymptotic equipartition theorem. Prerequisites: 178 or 278 or STATS 116, or equivalent.
*3 units, Win (Cover)*

**EE 376B. Information Theory**—Rate distortion theory and Kolmogorov complexity. Information theory and statistics. Stein's Lemma. AEP. Information capacity of networks. Slepian-Wolf Theorem. Optimal investment and information theory. Maximum entropy and Burg's Theorem. Prerequisite: 376A.
*3 units, Spr (Cover) alternate years, not given 2005-06*

**EE 377A. Dynamic Programming and Stochastic Control**—(Enroll in MS&E 351.)
*3 units, Spr (Veinott)*

**EE 377B. Approximate Dynamic Programming**—(Enroll in MS&E 339.)
*3 units, Win (Van Roy)*

**EE 378. Estimation and Detection**—Linear estimation: least-squares estimation, Wiener filtering, Kalman filtering. Detection: parametric and nonparametric hypothesis testing, detector structures, performance evaluation, sequential detection. Karhunen-Loeve expansion and applications to detection in continuous time. Bayesian and non-Bayesian parameter estimation. Maximum-likelihood estimation and the EM algorithm. Hidden Markov process state estimation. Modern theory: transform-based denoising, discrete denoising. Prerequisite: 278.
*3 units, Spr (Weissman)*

**EE 379A. Digital Communication I**—Maximum-likelihood data detection, modulation methods and bandwidth requirements, bandpass systems and analysis, intersymbol interference and equalization methods, diversity, phase-locking, and synchronization. Prerequisites: 102B, 278.
*3 units, Win (Cioffi)*

**EE 379B. Digital Communication II**—Basic channel capacity formulae, decoding algorithms: Viterbi detection, sequence detectors, and iterative decoding methods; partial-response methods, convolutional, trellis, turbo codes, and low-density parity check codes. Prerequisites: 278, 379A.
*3 units, Aut (Cioffi) alternate years, not given 2005-06*

**EE 379C. Advanced Digital Communication**—Multi-dimensional modulation and basis functions, transmit optimization for channels with intersymbol interference, discrete multitone (DMT), orthogonal frequency division multiplexing (OFDM), vector modulation, generalized decision-feedback equalization (GDFE).
*3 units, Spr (Cioffi) alternate years, not given 2005-06*

**EE 380. Seminar on Computer Systems**—Current research in the design, implementation, analysis, and use of computer systems ranging from integrated circuits to operating systems and programming languages.
*1 unit, Aut, Win, Spr (Allison, Long)*

**EE 381A. Database System Implementation**—(Enroll in CS 346.)
*3-5 units, Spr (Widom)*

**EE 381B. Transaction Processing and Distributed Databases**—(Enroll in CS 347.)
*3 units, Spr (Garcia-Molina)*

**EE 382A. Advanced Processor Architecture**—In-depth coverage of the microarchitecture of modern processors. Instruction set design, instruction-fetch techniques, data-fetch techniques, out-of-order and speculative execution, advanced pipelining, simultaneous multithreading, and low level compiler optimizations for instruction-level parallel processors. Basic principles and issues such as: instruction-level parallelism, data-flow execution, prediction, speculation, locality, performance-power-complexity trade-offs, workload characterization. Prerequisites: 108B, 282.
*3 units, Win (Kozyrakis)*

**EE 382B. Parallel Computer Architecture and Programming**—(Enroll in CS 315A.)
*3 units, Spr (Olukotun)*

**EE 382C. Interconnection Networks**—The architecture and design of interconnection networks used to communicate from processor to memory, from processor to processor, and in switches and routers. Topics: network topology, routing methods, flow control, router microarchitecture, and performance analysis. Enrollment limited to 30. Prerequisite: 282.
*3 units, Spr (Dally) alternate years, not given 2005-06*

**EE 383. Advanced Compiling Techniques**—(Enroll in CS 243.)
*3-4 units, Win (Staff)*

**EE 384A. Internet Routing Protocols and Standards**—Local area networks: MAC addressing; IEEE 802.1 bridging protocols (transparent bridging, virtual LANs). Internet routing protocols: Internet Protocol (IPv4, IPv6, ICMP); interior gateways (RIP, OSPF) and exterior gateways (BGP, policy routing); IP multicast (IGMP, DVMRP, CBT, MOSPF, PIM); multiprotocol label switching (MPLS). Prerequisite: 284 or CS 244A.
*3 units, Win (Tobagi)*

**EE 384B. Multimedia Communication over the Internet**—Applications and requirements.Traffic generation and characterization: voice encoding (G.711, G.729, G.723); image and video compression (JPEG, H.261, MPEG-2, H.263, H.264), TCP data traffic. Quality impairments and measures. Networking technologies: LAN technologies; home broadband services (ADSL, cable modems, PONs) and wireless LANs (802.11). Network protocols for multimedia applications: resource reservation (ST2+, RSVP); differentiated services (DiffServ); real-time transport protocol (RTP, RTCP). Audio-video-data conferencing standards: Internet architecture (SDP, SAP, SIP); ITU recommendations H. 320, H. 323 and T.120; real-time streaming protocol (RTSP). Prerequisite: 284 or CS 244A. Recommended: 384A.
*3 units, Spr (Tobagi) alternate years, not given 2005-06*

**EE 384C. Wireless Local Area Networks**—Basic characteristics of wireless communication: multipath, noise, and interference. Communications techniques: spread-spectrum, CDMA, and OFDM. IEEE 802.11 physical layer specifications: FHSS, DSSS, IEEE 802.11b (CCK), and 802.11a/g (OFDM). IEEE 802.11 media access control protocols: carrier sense multiple access with collision avoidance (CSMA/CA), point coordination function (PCF), IEEE802.11e for differentiated services. IEEE 802.11 network architecture: ad hoc and infrastructure modes, access point functionality. Management functions: synchronization, power management and association. Review of current research papers in the open literature. Prerequisite: 284 or CS244A.
*3 units (Tobagi) alternate years, given 2005-06*

**EE 384D. Projects in Computer Networks**—(Enroll in CS 344.)
*3 units, Spr (McKeown)*

**EE 384M. Network Algorithms**—Theory and practice of designing and analyzing algorithms arising in networks. Topics include: designing algorithms for load balancing, switching, congestion control, network measurement, the web infrastructure, and wireless networks; and analyzing the performance of algorithms via stochastic network theory. Algorithm design using randomization, probabilistic sampling, and other approximation methods. Analysis methods include the use of large deviation theory, fluid models, and stochastic comparison. Research project.
*3 units, Aut (Prabhakar)*

**EE 384N. Market Models for Network Resource Allocation**—(Enroll in MS&E 336.)
*3 units, Aut (Johari)*

**EE 384S. Network Architectures and Performance Engineering**—Modeling and control methodologies used in network performance engineering: Markov chains and stochastic modeling, queueing networks, stochastic simulation, dynamic programming, network optimization algorithms, large-scale distributed computation for networking operations. Applications to design issues in high-performance network architectures for wireline and wireless networking: traffic modeling, congestion control, IP network dynamics, TCP flow control, quality of service support, network admission control and operations management, power control and dynamic bandwidth allocation in wireless networks. Prerequisites: 284 and good understanding of probability and general systems modeling.
*3 units, Spr (Bambos)*

**EE 384X. Packet Switch Architectures I**—First of two-course sequence. Theory and practice of designing packet switches and routers. Evolution of switches and routers. Output scheduling: fairness, delay guarantees, algorithms. Unicast switching: blocking phenomena and their alleviation, connection between switch scheduling and bipartite graph matching. Multicast switching. Theoretical complements: simple queueing models, Bernoulli and Poisson processes, graph matching algorithms, urn problems, stability analysis using Lyapunov functions, fluid models. Prerequisites: 284 or CS 244A, 178 or 278 or STAT 116.
*3 units (McKeown, Prabhakar) not given 2004-05*

**EE 384Y. Packet Switch Architectures II**—Second of two-course sequence. The theory and practice of designing packet switches and routers. Address lookup: exact matches, longest prefix matches, performance metrics, hardware and software solutions. Packet classifiers: for firewalls, QoS, and policy-based routing; graphical description and examples of 2-D classification, examples of classifiers, theoretical and practical considerations.
*3 units (McKeown, Prabhakar) not given 2004-05*

**EE 385. Special Seminars in Computer Systems**—Given occasionally and usually announced 1 or 2 quarters in advance. See the *Time Schedule* and bulletins in the department office.
*1-4 units (Staff)*

**EE 385A. Digital Systems Reliability Seminar**—Student/faculty discussions of research problems in the design of reliable digital systems. Areas: fault-tolerant systems, design for testability, production testing, and system reliability. Emphasis is on student presentations and Ph.D. thesis research. Prerequisite: consent of instructor.
*1-4 units, Aut, Win, Spr, Sum (McCluskey)*

**EE 387. Error-Correcting Codes**—Theory and implementation of algebraic codes for detection and correction of random and burst errors. Introduction to finite fields. Linear block codes, cyclic codes, Hamming codes, Fire codes, BCH codes, Reed-Solomon codes. Decoding algorithms for BCH and Reed-Solomon codes. Prerequisites: elementary probability, linear algebra.
*3 units, Spr (Gill)*

**EE 390. Special Studies or Projects in Electrical Engineering**—Independent work under the direction of a faculty member. Individual or team activities may involve lab experimentation, design of devices or systems, or directed reading.
*1-15 units, by arrangement (Staff)*

**EE 391. Special Studies and Reports in Electrical Engineering**—Independent work under the direction of a faculty member; written report or written examination required. Letter grade given on the basis of the report; if not appropriate, student should enroll in 390.
*1-15 units, by arrangement (Staff)*

**EE 392. Special Seminars**

**EE 392A. Database Systems Principles**—(Enroll in CS 245.)
*3 units, Win (Garcia-Molina)*

**EE 392B. Introduction to Image Sensors and Digital Cameras**—Design and analysis of imaging sensors: silicon photodetectors; CCD and CMOS passive and active sensor operation; noise and FPN analysis; spatial resolution and MTF; SNR and dynamic range; high dynamic range architectures; A/D conversion approaches. Analysis of the signal path in a digital camera starting from the optics, through the sensor, the A/D converter, to the different color processing steps. MATLAB camera simulator is used to explore various tradeoffs in camera design. Prerequisites: undergraduate background in device, circuit, and system, equivalent to 102A, 101A,B; familiarity with noise analysis.
*3 units, Spr (El Gamal) alternate years, not given 2005-06*

**EE 392J. Digital Video Processing**—Spatio-temporal sampling, motion analysis, parametric motion models, motion-compensated filtering, and video processing operations including noise reduction, restoration, superresolution, deinterlacing and video sampling structure conversion, and compression (frame-based and object-based methods). Video segmentation and layered video representations, video streaming, compressed-domain video processing, and digital TV. Prerequisite: 368.
*3 units (Apostolopoulos) alternate years, given 2005-06*

**EE 392K. Genetic algorithms and Genetic Programming**—(Enroll in CS 426.)
*3 units, Aut (Koza)*

**EE 392O. Optimization Projects**—Project-based. Some topics not covered in 364, including subgradient methods, decomposition and decentralized convex optimization, exploiting problem structure in implementation, global optimization via branch and bound, and convex-optimization based relaxations. Applications in areas such as control, circuit design, signal processing, and communications. Substantial small group project. Prerequisite: 364 or consent of instructor. Limited enrollment.
*3 units (Boyd) alternate years, given 2005-06*

**EE 392Q. Mobile and Wireless Networks and Applications**—(Enroll in CS 444N.)
*3 units (Baker) not given 2004-05*

**EE 392R. Charged Particle Optics**—Electron optics of charged particle instruments including transmission electron microscope, scanning electron microscope and related tools, mass and energy spectrometers, electron beam lithography tools, focused ion beam systems, electron diffraction, proximal probe tools such as the scanning tunneling microscope. Topics include sources, first-order focusing of electrons and ions, third-order aberrations, space-charge effects and diffraction. Goal is to compute the optical parameters of axially-symmetric magnetic and electric lenses and to be familiar with the principles of operation of the above charged-particle systems and the factors limiting their performance. Prerequisites: undergraduate geometrical optics and vector calculus or 217.
*3 units (Pease) alternate years, given 2005-06*

**EE 392S. Sensor Network Seminar**—Silicon-based sensors, local computation, and the emerging technology of low power, ad hoc radio networks as enablers of networked sensing systems. Integration issues, information theory, and networking concerns suggest capabilities for smart sensing network nodes and system trade-offs. Human factors and practical considerations for widespread, consumer adoption of smart sensing networks. Future applications and barriers to adoption. Speakers from industry and academia.
*1 unit (Staff) not given 2004-05*

**EE 392T. Chip Test and Debug Seminar**—Seminars by industry professionals in digital IC manufacturing test and silicon debug. Topics include yield and binsplit modeling, defect types and detection, debug hardware, physical analysis, and design for test/debug circuits. Case studies of real silicon failures. Prerequisite: basic digital IC design equivalent to 271 or 371.
*3 units, Aut (Stinson)*

**EE 392X. Advanced Topics in Information Science and Technology**—(Enroll in MS&E 338.)
*3 units, Aut (Van Roy)*

**EE 395. Electrical Engineering Instruction: Practice Teaching**—Open to limited number of advanced EE graduate students who plan to make teaching their career. Students conduct a section of an established course taught in parallel by an experienced instructor.
*1-15 units, by arrangement (Gray)*

**EE 398. Image and Video Compression**—The principles of source coding for the efficient storage and transmission of still and moving images. Discrete Cosine Transform. Wavelet image coding. Interframe coding. Motion compensation and motion estimation. Emphasis is on rate distortion analysis and optimization of image and video coding schemes. Standards: JPEG, JPEG-2000, MPEG-1, MPEG-2, MPEG-4, H.261, H.263, H.264. Students investigate image and video compression algorithms in Matlab or C. Course is a condensed version of 398A/B sequence. Prerequisites: 261, 278.
*3 units, Win (Girod) alternate years, not given 2005-06*

**EE 398A. Image Communication I**—First of two-course series. Principles and systems for digital image communication, emphasizing source coding for efficient storage and transmission of still and moving images. Fundamentals and still image communication techniques. Lossless coding principles. Arithmetic coding, run-length coding. Facsimile coding. Lossy compression principles, scalar quantization, vector quantization. Lossless and lossy predictive coding. Transform coding. Multiresolution coding, subband coding, and wavelets. EZW and SPIHT coding. Embedded image representations. Standards: ITU-T T.4, T.6, JBIG, JPEG, JPEG-2000. Students investigate image compression algorithms in Matlab. Prerequisites: 261, 278.
*3 units (Girod) alternate years, given 2005-06*

**EE 398B. Image Communication II**—Second of two-course series. Digital video communication techniques. DPCM. Interframe coding. Motion-compensated prediction. Motion-compensated hybrid coding. Motion estimation. Rate distortion analysis and optimization of video coding schemes. Advanced motion compensation techiques. Scalable layered video representations. Error-resilient video coding. Applications: videotelephony, videoconferencing, digital TV broadcasting, Internet video streaming, wireless video. Standards: MPEG-1, MPEG-2, MPEG-4, ITU-T H.261, H.263, H264. Students investigate video compression algorithms in Matlab or C. Term project. Prerequisite: 398A.
*3 units (Girod) alternate years, given 2005-06*

**EE 400. Thesis and Thesis Research**—Limited to candidates for the degree of Engineer or Ph.D. Satisfactory/no credit.
*1-15 units, by arrangement (Staff)*

**EE 402A. Topics in International Technology Management**—Theme for 2004-05 is cross-border partnering in Asia: globalization challenges for high-tech industries. Off-shoring, outsourcing, and other collaborative cross-border activities, including international contract manufacturing and business process outsourcing, R&D partnerships, intellectual property management, and related issues and trends. Distinguished speakers from industry and government.
*1 unit, Aut (Dasher)*

**EE 402S. Topics in International Advanced Technology Research**—Theme for 2004-05 is novel integration in advanced electronic systems. New chip and board-level architectures, 3D ICs, integration of heterogeneous technologies and materials, e.g. bio-chips, MEMS, optoelectronic ICs, and similar topics. Distinguished speakers from industry, government, and universities. Prerequisite: none, but an understanding of basic electronics strongly recommended.
*1 unit, Spr (Dasher)*

**EE 402T. Entrepreneurship in Asian High Tech Industries**—Business and technology issues in the creation and growth of Asian startups, and patterns of entrepreneurship in Asia. Speakers include entrepreneurs, investors, inventors, and consultants, and others from government and academia.
*1 unit, Spr (Dasher)*

**EE 410. Integrated Circuit Fabrication Laboratory**—Fabrication, simulation, and testing of a highly simplified 1.5 micron CMOS process developed for this course. Practical aspects of IC fabrication including silicon wafer cleaning, photolithography, etching, oxidation, diffusion, ion implantation, chemical vapor deposition, physical sputtering, and wafer testing. Students perform simulations of the CMOS process using process simulator TSUPREM4 of the structures and electrical parameters that should result from the process flow in the lab. Taught in the Stanford Nanofabrication Facility (SNF) in the Center for Integrated Systems (CIS). Preference to students pursuing doctoral research program requiring SNF facilities. Enrollment limited to 20. Prerequisites: 212, 216, consent of instructor.
*3-4 units, Win (Saraswat)*

**EE 414. Design of Discrete RF Circuits for Communications Systems**—Students design, build, and test GHz transceivers using microstrip construction techniques and discrete components. The design, construction, and experimental characterization of representative transceiver building blocks: low noise amplifiers (LNAs), diode ring mixers, PLL-based frequency synthesizers, voltage-controlled oscillators (VCOs), power amplifiers (PAs), and microstrip filters and patch antennas. The characteristics of passive microstrip components (including interconnect). Emphasis is on a quantitative reconciliation of theoretical predictions and extensive experimental measurements performed with spectrum and network analyzers, time-domain reflectometers (TDRs), noise figure meter and phase noise analyzers. Prerequisites: 314, 344.
*3 units, Spr (Lee)*

**EE 418. Topics in Neuroengineering**—Selected topics in neuroscience and electrical engineering, focusing on principles and theory used in modern neural prosthetic systems (brain-computer or brain-machine interfaces). Electrical properties of neurons, information encoding, neural measurement techiques and technology, processing electronics, information decoding and estimators, and statistical data analysis. Prerequisites: 214, 278.
*3 units, Win (Shenoy) alternate years, not given 2005-06*

**EE 469A. In Vivo Magnetic Resonance Spectroscopy and Imaging**—(Enroll in RAD 226.)
*3 units, Win (Spielman)*

**EE 469B. RF Pulse Design for Magnetic Resonance Imaging**—Magnetic resonance imaging (MRI) and spectrscopy (MRS) are based on the use of radio frequency pulses to manipulate magnetization. Analysis and design of major types of RF pulses in one and multiple dimensions, analysis and design of sequences of RF pulses for fast imaging, and use of RF pulses for the creation of image contrast in MRI. Prerequisite: 369B.
*3 units, Aut (Pauly) alternate years, not given 2005-06*

**EE 477. Universal Schemes in Information Theory**—Universal schemes for lossless and lossy compression, channel coding and decoding, prediction, denoising, and filtering. Characterization of performance limitations in the stochastic settting: entropy rate, rate-distortion function, channel capacity, Bayes envelope for prediction, denoising, and filtering. Lempel-Ziv lossless compression, and Lempal-Ziv based schemes for lossy compression, channel coding, prediction, and filtering. Discrete universal denoising. Compression-based approach to denoising. The compound decision problem. Prerequisites: 278, 376A,B.
*3 units, Aut (Weissman)*

**EE 478. Topics in Multiple User Information Theory**—Topics in multiple user source and channel coding; multiple access channel, correlated source coding, broadcast channel, interference channel, relay channel, and channels with feedback; asymptotic capacity of networks; source coding with side information, multiple descriptions, channels with state, MIMO channels. Prerequisite: 376A.
*3 units (El Gamal) alternate years, given 2005-06*

**EE 479. Multiuser Digital Transmission Systems**—Multiuser communications design, modulation, and reception. Capacity regions and fundamentally optimum designs for multiple access, broadcast, and interference channels. Multiuser detection, crosstalk, matrix channel descriptions, iterative waterfilling, vectoring, and multi-user generalized decision feedback equalization (GDFE). Prerequisite: 379C.
*3 units (Cioffi) alternate years, given 2005-06*

**EE 481A. Computer Graphics: Geometric Modeling**—(Enroll in CS 348A.)
*3-4 units, Win (Guibas)*

**EE 481B. Computer Graphics: Image Synthesis Techniques**—(Enroll in CS 348B.)
*3-4 units, Spr (Hanrahan)*

**EE 482A Advanced Computer Organization: Processor Microarchitecture**—High-performance computer design focusing on the microarchitecture of high-performance processors. Topics: pipelining, memory systems, out-of-order issue, branch prediction, and vector processors. Design project. Enrollment limited to 30. Prerequisite: 282.
*3 units (Dally) alternate years, given 2005-06*

**EE 483. Advanced Topics in Compilers**—(Enroll in CS 343.)
*3 units (Lam) not given 2004-05*

**EE 484. Topics in Computer Graphics**—(Enroll in CS 448.)
*3-4 units, by arrangement (Staff)*

**EE 485. Broad Area Colloquium for Artificial Intelligence, Geometry, Graphics, Robotics, and Vision**—(Enroll in CS 528.)
*1 unit, Aut, Win, Spr (Thrun)*

**EE 486. Advanced Computer Arithmetic**—Number systems, floating point representation, state of the art in arithmetic algorithms, problems in the design of high speed arithmetic units. Prerequisite: 282.
*3 units (Flynn) alternate years, given 2005-06*

**EE 487. Communication SoC Design**—Design and implementation of signal processing systems in systems on a chip (SoC) using state-of-the-art integrated circuit technology. Architecture, performance area, and energy efficiencies for various applications. Related topics such as digital communication, the modeling of analog subsystems and their impairments, and the incorporation of flexibility into the design. Wireless system design provides a concrete realization of all issues to be addressed in an SoC design. Prerequisites: 265, 271.
*3 units, Spr (Meng) alternate years, not given 2005-06*

**EE 488. Testing Aspects of Computer Systems**—The fundamental principles of testing computer systems and designing for testability. Failure and fault models. Deterministic and probabilistic techniques of test generation and testing. Techniques for testing memories and microprocessors. Design for testability. Prerequisite: 275.

*3 units (McCluskey) alternate years, given 2005-06*

**EE 492. Special Seminars**

**EE 492M. Space-Time Wireless Communications**—For EE graduate students and wireless systems engineers. Space-time (ST) wireless communications offer performance improvements in capacity, coverage, and quality. Aspects of ST technology are already part of 2.5G/3G systems. More advanced aspects (MIMO) are being incorporated into several standards. Prerequisites: 276, 278, 279. Recommended: 359.

*3 units (Paulraj) alternate years, given 2005-06*

## OVERSEAS STUDIES

Courses approved for the Electrical Engineering major and taught overseas can be found in the "Overseas Studies" section of this bulletin, or in the Overseas Studies office, 126 Sweet Hall.

### KYOTO

**EE 69. Undergraduate Seminar on Medical Imaging Systems**

*3 units, Spr (Nishimura)*

**EE 261. The Fourier Transform and its Applications**

*3 units, Spr (Nishimura)*

# MANAGEMENT SCIENCE AND ENGINEERING

*Emeriti: (Professors)* James L. Adams, Kenneth J. Arrow, George B. Dantzig, Donald A. Dunn, B. Curtis Eaves, Frederick S. Hillier, Donald L. Iglehart, James V. Jucker, Alan S. Manne, Michael M. May, Robert V. Oakford, Henry E. Riggs, David A. Thompson

*Chair:* M. Elisabeth Paté-Cornell

*Deputy Chairs:* Thomas H. Byers, Peter W. Glynn

*Professors:* Nicholas Bambos, Stephen R. Barley, Margaret L. Brandeau, Robert C. Carlson, Richard W. Cottle, Kathleen M. Eisenhardt, Peter W. Glynn, Warren H. Hausman, Ronald A. Howard, David G. Luenberger, M. Elisabeth Paté-Cornell, William J. Perry, Robert I. Sutton, James L. Sweeney, Arthur F. Veinott, Jr., Yinyu Ye

*Associate Professors:* Samuel S. Chiu, Ross D. Shachter, Edison T. S. Tse

*Assistant Professors:* Diane E. Bailey, Feryal Erhun, Ashish Goel, Pamela J. Hinds, Ramesh Johari, Riitta Katila, Ozalp Ozer, James A. Primbs, Benjamin Van Roy, Thomas A. Weber

*Professors (Research):* Walter Murray, Michael A. Saunders, John P. Weyant

*Professors (Teaching):* Thomas H. Byers, Robert E. McGinn

*Consulting Professors:* Hung-Po Chao, Thomas Kosnik, James E. Matheson, Robert R. Maxfield, D. Warner North, Sam Savage

*Consulting Associate Professors:* Stephen Barrager, Corey Billington, Adam Borison, Peter Haas, Samuel Holtzman, Gerd Infanger, Randy Komisar, Michael Lyons, Audrey MacLean, Burke Robinson, Adam Seiver, F. Victor Stanton, Behnam Tabrizi

*Consulting Assistant Professors:* Blake E. Johnson, Hervé Kieffel, Barchi Peleg

*Lecturers:* Mark Leslie, Robert Luenberger, Doug MacKenzie, Mary Morrison, Tina Seelig

*Visiting Professors:* Sultan Bhimjee, Olivier de La Grandville

*Visiting Associate Professors:* Charles Feinstein, Yee-Tien Fu

*Visiting Lecturer:* Ferdo Ivanek

*Co-Directors of the Industrial Affiliates Program:* Margaret L. Brandeau, Yinyu Ye

*Affiliated Faculty:* Anat Admati, David Beach, Darrell Duffie, J. Michael Harrison, Charles A. Holloway, Kosuke Ishii, James G. March, David B. Montgomery, Evan L. Porteus, Balaji Prabhakar, Krishna Saraswat, Sheri Sheppard

*Department Offices:* Terman Engineering Center

*Mail Code:* 94305-4026

*Web Site:* http://www.stanford.edu/dept/MSandE

Courses given in Management Science and Engineering have the subject code MS&E. For a complete list of subject codes, see Appendix.

In December 1999, the Board of Trustees authorized the creation of the Department of Management Science and Engineering from the Department of Industrial Engineering and Engineering Management and the Department of Engineering-Economic Systems and Operations Research. Its main objective is to be the leader among academic departments, at the interface of engineering, business, and public policy. The department's mission is to conduct research and provide education associated with the development of the knowledge, tools, and methods required to make decisions and shape policies, configure organizational structures, design engineering systems, and solve operational problems associated with the information-intensive, technology-based economy.

Management Science and Engineering (MS&E) provides exceptionally strong programs of education and research by integrating three basic strengths: (1) substantial depth in conceptual and analytical foundations, (2) comprehensive coverage of functional areas of application, and (3) vigorous interaction with other Stanford departments, with Silicon Valley industry, and with many organizations throughout the world. The analytical and conceptual foundations include optimization, dynamic systems, stochastic systems, economics, organizational science, and decision and risk analysis. These foundations support the functional areas and provide the basis for further advance in the discipline. The functional areas of application include finance, production, information, organizational behavior, marketing, entrepreneurship, policy, and strategy. Programs in these functional areas emphasize both fundamental concepts and practical applications. Close associations with other engineering departments and with industry enrich the programs by providing opportunities to apply MS&E methods to important problems and by motivating new theoretical developments from practical experience. MS&E's programs also provide a basis for contributing to other important areas such as biotechnology, defense policy, environmental policy, information systems, telecommunications, and other areas where mastery of fundamentals, functional knowledge, and an engineering viewpoint are extremely valuable.

## CAREERS IN MS&E

MS&E helps students prepare for a variety of professional careers in business, government, industry, non-profit institutions, and universities. Graduates have pursued successful careers in consulting, enterprise management, financial analysis, government policy analysis, industrial research, line management, product development, project management, strategic planning, and university teaching and research. Some have founded companies specializing in financial services, high technology products, management and systems consulting, or software. Other graduates have helped establish new analytical capabilities in existing firms or government agencies.

Many graduates have become leaders in technology-based businesses, which have an increasing need for well-educated, analytically oriented people who understand both business and technology. The Department of MS&E is attractive to people with engineering, mathematical science, and physical science backgrounds as it complements their technical abilities with the conceptual frameworks needed to analyze problems of investment, management, marketing, operations, production, and strategic planning in a technical environment.

## UNDERGRADUATE PROGRAMS

### BACHELOR OF SCIENCE

The program leading to the B.S. degree in Management Science and Engineering (MS&E) is stated earlier under the "School of Engineering" section of this bulletin, and more information is contained in the School of Engineering's *Handbook for Undergraduate Engineering Programs*. Students are encouraged to plan their academic programs as early as possible, ideally in the freshman or sophomore year. Please do not wait until you are declaring a major to consult with the department's student services staff. This is particularly important if you would like to study overseas or pursue another major or minor.

The undergraduate curriculum in Management Science and Engineering provides students training in the fundamentals of engineering systems analysis to prepare them to plan, design, and implement complex economic and technological management systems where a scientific or engineering background is necessary or desirable. Graduates will be prepared for work in a variety of career paths, including facilities and process management, investment banking, management consulting, or graduate study in industrial engineering, operations research, economics, public policy, medicine, law, or business.

The educational objectives of the undergraduate degree program are:

1. *Principles and Skills:* provide students with a basic understanding of management science and engineering principles, including analytical problem solving and communications skills.
2. *Preparation for Practice:* prepare students for practice in a field that sees rapid changes in tools, problems, and opportunities.
3. *Preparation for Continued Growth:* prepare students for graduate study and self development over an entire career, and
4. *Preparation for Service:* develop in students the awareness, background, and skills necessary to become responsible citizens, employees, and leaders.

In particular, the department wants to help students develop:

a) an ability to apply knowledge of math, science, and engineering.
b) an ability to design and conduct experiments.
c) an ability to design a system or components to meet desired needs.
d) an ability to identify, formulate, and solve engineering problems.
e) an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice.
f) an ability to function on multidisciplinary teams.
g) an ability to communicate effectively.
h) a recognition of the need for and an ability to engage in life-long learning.
i) background necessary for admission to top professional graduate engineering or business programs.
j) an understanding of professional and ethical responsibility.
k) the broad education necessary to understand the impact of engineering solutions in a global and societal context.
l) a knowledge of contemporary issues pertinent to the field of management science and engineering.

The program builds on the foundational courses for engineering, including calculus, engineering fundamentals, and physics or chemistry.

The department core, taken for all concentrations, includes courses in computer science, deterministic optimization, information, organization theory, a senior project, and finance or production. Through the core, all students in the program are exposed to the breadth of faculty interests, and are in a good position to choose a concentration during the junior year.

The five concentrations are designed to allow a student to explore one area of the department in greater depth.

1. *Financial and Decision Engineering:* focuses on the design and analysis of financial and strategic plans. It features accounting, decision analysis, economics, finance, investment science, and stochastic models.
2. *Operations Research:* provides a more mathematical program, based on algorithms, theory, and applications in economics and operations.
3. *Organization, Technology, and Entrepreneurship:* designed for students seeking a broad technological background coupled with understanding the behavior of individuals and groups. It features courses exploring technology-based organizations.
4. *Production and Operations Management:* focuses on the design and analysis of manufacturing, production, and service systems.
5. *Technology and Policy:* designed for students seeking a broad technological background coupled with policy analysis. It features courses in microeconomics, public policy, ethics or the law, and applications in national security and commertical technology policy.

For information about an MS&E minor, see the "School of Engineering" section of this bulletin.

MS&E also participates with the departments of Computer Science, Mathematics, and Statistics in a program leading to a B.S. in Mathematical and Computational Science. See the "Mathematical and Computational Science" section of this bulletin.

## GRADUATE PROGRAMS

MS&E, in collaboration with other departments of the University, offers programs leading to the degrees of Master of Science and Doctor of Philosophy. The department also offers a coterminal B.S./M.S. degree, and a dual master's degree in cooperation with each of the other departments in the School of Engineering.

For University coterminal degree program rules and University application forms, see http://registrar.stanford.edu/publications/#Coterm.

Applicants for admission as graduate students in MS&E must submit the results of the verbal, quantitative, and analytical parts of the Graduate Record Examination. The deadline for application is January 4 for doctoral applicants, and January 11 for masters applicants.

Except in unusual circumstances, admission is limited to the Autumn Quarter because courses are arranged sequentially with basic courses and prerequisites offered early in the academic year.

*Assistantships and Fellowships*—A limited number of fellowships and assistantships are awarded each year. Applicants admitted to the doctoral program, who have indicated on their application that they would like to be considered for financial aid, are automatically considered for these assistantships and fellowships.

Information about loan programs and need-based aid for U.S. citizens and permanent residents can be obtained from the Financial Aid Office.

## MASTER OF SCIENCE

The M.S. degree programs require a minimum of 45 units beyond the equivalent of a B.S. degree at Stanford. All programs represent substantial progress in the major field beyond the bachelor's degree.

University requirements for the master's degree are described in the "Graduate Degrees" section of this bulletin.

### MANAGEMENT SCIENCE AND ENGINEERING

The M.S. program in Management Science and Engineering (MS&E) prepares individuals for a lifelong career addressing critical technical and managerial needs in private and public decision making. Department requirements for the M.S. degree provide breadth across some of the areas of the department, and flexibility for meeting individual objectives of depth in a particular area of concentration. The master's degree may be a terminal degree program with a professional focus, or a preparation for a more advanced graduate program. The M.S. degree can normally be earned in one academic year (three academic quarters) of full-time work, although students may choose to continue their education by taking additional MS&E courses beyond that year. Background requirements, taken in addition to degree requirements, must be met by students who have had insufficient course work in mathematical sciences, computer science, engineering and/or natural sciences.

Students must take a minimum of 45 course units as follows:

1. At least five core courses
2. At least three other courses in an area of concentration of their choice
3. A course in probability, unless a college-level course in probability has already been passed
4. A project course requirement
5. The remaining units in elective courses

*Background Requirements*—Students must have had or must take the following (or equivalent) courses before the M.S. degree is conferred: MATH 41, 42, 51 (Calculus, 15 units), CS 106A (programming, 5 units), and an additional 15 units of engineering, mathematical sciences, or natural sciences. These courses do not count toward the 45 units of the M.S. degree. Courses taken to meet MS&E background requirements may be at either the undergraduate or graduate level, and may be taken as credit/no credit. These additional background requirements would typically be met by students who have a bachelor's degree in engineering, or mathematical or natural sciences. Students are notified at the time of admission of any remaining need to meet background requirements.

*Core Courses*—M.S. students must take at least five courses out of the following ten options:

Decision Analysis (MS&E 252), or Risk Analysis (MS&E 250A)
Dynamic Systems (MS&E 201) or Stochastic Decision Models (MS&E 251)
Economic Analysis (MS&E 241)
Global Entrepreneurial Marketing (MS&E 271)
Industrial Accounting (MS&E 240), Investment Science (MS&E 242), or Introduction to Finance (MS&E 245G)
Introduction to Stochastic Modeling (MS&E 221) or Simulation (MS&E 223)
Linear and Non-Linear Optimization (MS&E 211)
Organizational Behavior and Management (MS&E 280)
Production Systems (MS&E 261)
Strategy in Technology-Based Companies (MS&E 270)

Students may not waive core courses. They may, however, petition to substitute an approved, more advanced course in the same area. Courses used to satisfy the core requirement must be taken for a letter grade, must be taken for a minimum of three units each, and may not also be used to satisfy the concentration requirement.

*Courses in an Area of Concentration*—Students must complete a departmentally approved set of three or more letter-graded courses taken for a minimum of three units each, in an area of concentration of one of the following types:

1. An area of concentration in the MS&E department
2. An area of concentration in one of the seven other departments of the School of Engineering
3. In exceptional cases, a coherent area of concentration designed by the student. Petitions for student-designed concentrations must list the three proposed courses (taken for three units or more and at the 200-level or above) and include a brief justification. The petition must be submitted to student services no later than the fifth week of the quarter prior to graduation.

*Project Course Requirement*—Students must take either a designated project course or two designated integrated project courses. The project course(s) must be taken for letter grade, must be taken for a minimum of three units, and may also be used to satisfy the core or concentration requirement.

Additional requirements are:

1. At least 45 units must be in courses numbered 100 and above
2. At least 27 units must be in courses numbered 200 and above in MS&E, taken for a letter grade and a minimum of two units each, and at least 36 letter-graded units must be in MS&E or closely related fields. Closely related fields include any department in the School of Engineering, mathematics, statistics, economics, sociology, psychology, or business.
3. The degree program must be completed with a grade point average (GPA) of 3.0 or higher.
4. A maximum of three units of language courses (numbered 100 and above)
5. A maximum of three units of 1-unit courses such as seminars, colloquia, workshops, in any department, and a maximum of one unit of MS&E 208, Curricular Practical Training.
6. A maximum of 18 Non-Degree Option (NDO) units through the Stanford Center for Professional Development (SCPD)
7. Courses in athletics may not be applied toward the degree.

Please see the student services office or department web site for complete listing of project, integrated project and approved concentrations.

### DUAL MASTER'S DEGREE

*Admission*—For the dual degree, admission to two departments is required, but is coordinated by designated members of both Admissions Committees who make recommendations to the committees of their respective departments. Students may apply to only one Department initially. After the first quarter at Stanford, students may apply to be admitted to the second Department.

*Advising*—Every student in the dual degree program has one adviser in each department.

*The Dual Degree Program*—This dual degree program enables a small, selective set of graduate students to obtain two master's degrees simultaneously. Students complete the course requirements for each department. A total of 90 units is required to complete the dual master's degree.

## PROFESSIONAL EDUCATION

The Stanford Center for Professional Development (SCPD) provides opportunities for employees of some local and remote companies to take courses at Stanford.

The Honors Cooperative Program (HCP) provides opportunities for employees of SCPD Member companies to earn an M.S. degree, over a longer period, by taking one or two courses per academic quarter. Some courses are only offered on campus; HCP students may attend those courses at Stanford to meet the degree requirements. It is possible to complete this program as a remote HCP student although the remote offerings are limited. Students must apply for a degree program through the standard application process, and must meet the standard application deadline of January 11.

The Non-Degree Option (NDO) allows employees of some local companies to take courses for credit from their company sites before being admitted to a degree program. Students apply to take NDO courses each quarter through the Stanford Center for Professional Development. Up to 18 units taken as an NDO student may be applied toward a degree program.

For additional information about the NDO application process and deadlines, see http://scpd.stanford.edu, or contact SCPD at (650) 725-3000.

The department offers a Certificate Program within the framework of the NDO program. A certificate can be obtained by completing three MS&E core courses, plus one MS&E elective course for a total of four courses. For further information, see: http://scpd.stanford.edu/scpd/programs/certs/managementSci.htm.

## DOCTOR OF PHILOSOPHY

University requirements for the Ph.D. degree are described in the "Graduate Degrees" section of this bulletin.

The Ph.D. degree in MS&E is intended for students primarily interested in a career of research and teaching, or high-level technical work in universities, industry, or government. The program requires three years of full-time graduate study, at least two years of which must be at Stanford. Typically, however, students take about four to five years after entering the program to complete all Ph.D. requirements. The Ph.D. is generally organized around the requirement that the students acquire a certain breadth across some of the eight areas of the department, and depth in one of them. These areas are:

Decision analysis and risk analysis
Economics and finance
Information science and technology
Organization, technology, and entrepreneurship
Policy and strategy
Probability and stochastic systems
Production and operations management
Systems modeling and optimization

Doctoral students are required to take a number of courses, both to pass a qualifying exam in one of these areas, or the Systems Program which is a combination of several areas, and to complete a dissertation based on research which must make an original contribution to knowledge.

Each student admitted to the Ph.D. program must satisfy a breadth requirement and pass a qualification procedure. The purpose of the qualification procedure is to assess the student's command of the field and to evaluate his or her potential to complete a high-quality dissertation in a timely manner. The student must complete specified course work in one of the eight areas of the department, or the Systems Program which is a combination of several areas. The qualification decision is based on the student's grade point average (GPA), on the one or two preliminary papers prepared by the student, and on the student's performance in an area examination. Considering this evidence, the department faculty votes on advancing the student to candidacy in the department at large. The Ph.D. requires a minimum of 135 units, at least 54 of which must be in courses of 3 units or more. At least 48 course units in courses of 3 units or more must be taken for a letter grade. Finally, the student must pass a University oral examination and complete a Ph.D. dissertation. During the course of the Ph.D. program, students who do not have a master's degree are strongly encouraged to complete one, either in MS&E or in another Stanford department.

*Breadth Requirement*—

1. The breadth requirement is to be satisfied by a choice of four courses spanning four out of the above mentioned eight areas of the department. The list of courses satisfying the breadth requirement is available from the MS&E student services office.
2. The Ph.D. candidacy form must contain four courses that satisfy the breadth requirement.
3. Courses chosen to satisfy the breadth requirement must be taken for letter grades.
4. At least one of the four courses chosen to satisfy the breadth requirement must be at the 300 level.

*Qualification Procedure Requirements*—The qualification procedure is based both on breadth across the department's disciplines and depth in an area of the student's choice. The qualification process must be completed by the end of the month of May of the student's second year of graduate study in the department. The performance of all doctoral students is reviewed every year at a department faculty meeting at the end of May or beginning of June. Ph.D. qualification decisions are made at that time and individual feedback is provided.

The Ph.D. qualification requirements comprise three elements:

1. *Grade Point Average:* a student must maintain a GPA of at least 3.4 in the four courses chosen to satisfy the breadth requirements, and a GPA of at least 3.4 in the set of all courses taken by the student within the department. In both cases, the GPA is computed on the basis of the nominal number of units for which each course is offered.
2. *Paper(s):* a student may choose between two options, either to be completed before the Spring Quarter of the student's second year. The first option involves one paper supervised by a primary faculty adviser and a faculty consultant. This paper should be written in two quarters.

   The second option involves two shorter sequential tutorials, with two different faculty advisers. Each tutorial should be completed in one quarter. In both options, the student chooses the faculty adviser(s)/consultant with the faculty members' consent.

   A student may register for up to 3 units per tutorial and up to 6 units for a paper. These paper or tutorial units do not count towards the 54 course units required for the Ph.D., and letter grades are not given.
3. *Area Qualification:* in addition, during the second year, a student must pass an examination in one of the eight areas of the MS&E department or the Systems Program which is a combination of several areas, which will be of his or her choice. This area examination is written, oral, or both at the discretion of the area faculty administering the exam.
4. *Area Course Requirement:* students must complete the depth requirements of one of the eight areas of the MS&E department or the Systems Program which is a combination of several areas. All courses used to satisfy depth requirements must be taken for a letter grade. The Ph.D. requirements for the eight areas of the MS&E department are available from the MS&E student services office.

## COURSES

WIM indicates that the course satisfies the Writing in the Major requirements. (AU) indicates that the course is subject to the University Activity Unit limitations for undergraduates (8 units maximum).

## UNDERGRADUATE

**MS&E 41. Financial Literacy**—Practical knowledge about personal finance and money management including budgeting, pay checks, credit cards, banking, insurance, taxes, and saving. Class especially appropriate for those soon to be self-supporting. Limited enrollment.
*1 unit, Win, Spr (Morrison)*

**MS&E 60. Engineering Economy**—(Enroll in ENGR 60.)
*3 units, Win (Chiu), Spr (Weber), Sum (Bhimjee)*

**MS&E 92Q. International Environmental Policy**—Stanford Introductory Seminar. Preference to sophomores. The science, economics and, politics of international environmental policy. Current negotiations on global climate change. Lectures and materials similar to material the instructor used in briefing international negotiations and the U.S. Congress, integrating the material in policy briefings on individuals, dimensions, or the problem and potential solutions.
*4 units, Spr (Weyant)*

**MS&E 93Q. Nuclear Weapons, Terrorism, and Energy**—Stanford Introductory Seminar. Preference to sophomores. What are nuclear weapons and what do they do? Why do some nations want them? What are the risks of nuclear terrorism? What is radioactivity? What role does nuclear power play? Can it help with global warming? Emphasis is on policy options in the light of changes in the world. Recommended: a course in economics, engineering, or physical science. GER:2b
*3 units, Spr (May)*

**MS&E 101. Undergraduate Directed Study**—Subject of mutual interest to the student and faculty member. Prerequisite: faculty sponsor.
*1-15 units, Aut, Win, Spr, Sum (Staff)*

**MS&E 107. Interactive Management Science**—(Graduate students register for 207.) Analytical techniques such as linear and integer programming, Monte Carlo simulation, forecasting, decision analysis, and Markov chains in the environment of the spreadsheet. Materials include spreadsheet add-ins for implementing these and other techniques. Emphasis is on building intuition through interactive modeling, and extending the applicability of this type of analysis through integration with existing business data structures. Project required of those enrolled in 207. GER:2b
*3 units, Aut (Savage)*

**MS&E 108. Senior Project**—Restricted to MS&E majors in their senior year. Students carry out a major project in groups of four, applying techniques and concepts learned in the major. Project work includes problem identification and definition, data collection and synthesis, modeling, development of feasible solutions, and presentation of results.
*5 units, Win (Bailey, Hausman, Shachter)*

**MS&E 111. Introduction to Optimization**—(Enroll in ENGR 62.)
*4 units, Aut (Veinott), Spr (Van Roy)*

**MS&E 112. Mathematical Programming and Combinatorial Optimization**—(Graduate students register for 212; see 212; same as CME 208.)
*3 units, Spr (Goel)*

**MS&E 120. Probabilistic Analysis**—Concepts and tools for the analysis of problems under uncertainty, focusing on model building and communication: the structuring, processing, and presentation of probabilistic information. Examples from legal, social, medical, and physical problems provide motivation and illustrations of modeling techniques. Spreadsheets used to illustrate and solve problems as a complement to analytical closed-form solutions. Topics: axioms of probability, probability trees, random variables, distributions, conditioning, expectation, change of variables, and limit theorems. Prerequisite: MATH 51. Recommended: knowledge of spreadsheets. GER:2b
*5 units, Aut (Chiu)*

**MS&E 121. Introduction to Stochastic Modeling**—Stochastic processes and models in operations research. Discrete and continuous time parameter Markov chains. Queuing theory, inventory theory, simulation. Prerequisite: 120 or Statistics 116. GER:2b
*4 units, Win (Glynn)*

**MS&E 130. Information Systems**—(Graduate students register for 231.) Introduction to design and applications of computer-based information systems. Topics: database design; computer networks; computer security; search engines and information retrieval; technical and social issues in peer-to-peer systems; reputation systems; information systems for organizations. Interplay between policy and technical issues through guest lectures and class project.
*4 units, Aut (Goel)*

**MS&E 131. Information Science**—Five essential aspects of information science. Information as entropy: bits and bytes, channel capacity, compression, and coding. Information as an economic commodity: how information goods are produced, sold, distributed, and valued. Information as encrypted: classical and modern methods. Information as extracted from data: mining, modeling, and estimation. Information as emitted: information theory underlying telephone, radio, television, and cell phones. Theory, applications, and demonstrations. GER:2b
*3 units, Win (Luenberger)*

**MS&E 134. Organizations and Information Systems**—(Graduate students register for 234.) How information systems impact organizations and how organizations take control of information technology (IT) to gain a competitive edge. Topics include: IT components, architecture, and transformation; the effect of IT on competition; real-time enterprise; leadership; and outsourcing. Student teams perform field studies based on situations in which information technology is creating a significant management problem or business opportunity. Prerequisites: CS 106A, 180, or equivalents.
*4 units, Win (Tabrizi)*

**MS&E 140. Industrial Accounting**—(Graduate students register for 240.) Non-majors and minors who have taken or are taking elementary accounting should not enroll. Introduction to accounting concepts and the operating characteristics of accounting systems. The principles of financial and cost accounting, design of accounting systems, techniques of analysis, and cost control. Interpretation and use of accounting information for decision making. For the user of accounting information and not as an introduction to a professional accounting career.
*4 units, Aut, Sum (Stanton)*

**MS&E 142. Investment Science**—Theory and application of modern quantitative investment analysis. How investment concepts are used to evaluate and manage opportunities, portfolios, and investment products including stocks, bonds, mortgages, and annuities. Topics: deterministic cash flows (time-value of money, present value, internal rate of return, term structure of interest rates, bond portfolio immunization, project optimization); mean-variance theory (Markowitz model, capital asset pricing); and arbitrage pricing theory. Group project. Prerequisites: 120, ENGR 60, MATH 51, or equivalents. Recommended: 140, ENGR 62, knowledge of spreadsheets.
*3 units, Aut (Primbs)*

**MS&E 152. Introduction to Decision Analysis**—How to make good decisions in a complex, dynamic, and uncertain world. People often make decisions that on close examination they regard as wrong. Decision analysis uses a structured conversation based on actional thought to obtain clarity of action in a wide variety of domains. Topics: distinctions, possibilities and probabilities, relevance, value of information and experimentation, relevance and decision diagrams, risk attitude. Students seeking to fulfill the Writing in the Major requirement should register for MS&E 152W. GER:2b
*3-4 units, Spr (Shachter)*

**MS&E 152W. Introduction to Decision Analysis**—(Same as 152.) For students seeking to fulfill the Writing in the Major requirement. GER:2b,WIM
*4 units, Spr (Shachter)*

**MS&E 153. Introduction to Decision Making in Organizations**—Experienced management consultants share lessons and war stories. Case studies, disguised examples from real engagements, and movie clips illustrate theories and concepts of decision analysis. Student teams critique decisions made in actual organizations. Topics include: what makes a good decision, how decisions can be made better, framing and structuring techniques, modeling and analysis tools, biases and probability assessment, evaluation and appraisal methods, and effective presentation styles. GER:2b
*3 units, Sum (Robinson, Holtzman)*

**MS&E 160. Analysis of Production and Operating Systems**—(Graduate students register for 260; see 260.)
*4 units, Aut (Ozer)*

**MS&E 164. Manufacturing Systems Design**—(Graduate students register for 264; see 264.)
*3 units, Aut (Erhun)*

**MS&E 169. Quality Engineering: Qualitative Concepts and Statistical Analysis**—(Graduate students register for 269; see 269.)
*4 units, Win (Brandeau)*

**MS&E 175. Innovation, Creativity, and Change**—Problem solving in organizations; creativity and innovation skills; thinking tools; creative organizations, teams, individuals, and communities.
*4 units, Win (Katila)*

**MS&E 180. Organizations: Theory and Management**—For undergraduates only, with preference to MS&E majors. Survey of classical and contemporary organization theory, covering the behavior of the individuals, groups, and organizations. Limited enrollment. Students must attend first session.

*4 units, Aut (Eisenhardt), Spr (Hinds)*

**MS&E 181. Issues in Technology and Work for a Post-Industrial Economy**—How changes in technology and organization are altering work and lives. Approaches to studying and designing work. How understanding work and work practices can assist engineers in designing better technologies and organizations. Topics include job design, distributed and virtual organizations, the blurring of boundaries between work and family life, computer supported cooperative work, trends in skill requirements and occupational structures, monitoring and surveillance in the workplace, downsizing and its effects on work systems, project work and project-based lifestyles, the growth of contingent employment, telecommuting, electronic commerce, and the changing nature of labor relations.

*3 units, Spr (Barley)*

**MS&E 184. Technology and Work**—Theory and research on the social implications of technology and technological change for workers at all levels. Alternate conceptions of technology as social phenomenon, approaches to the study of workplace technology, individual and group reactions to technological change, the construction of a technology's social meaning, and management of technological change. Emphasis is on automation, electronic data processing, and microelectronic technologies including CAD-CAM systems, telecommunication networks, medical imaging, artificial intelligence, and personal computers.

*3 units, Aut (Bailey)*

**MS&E 193. Technology and National Security**—(Graduate students register for 293.) The interaction of technology and national security policy from the perspective of history to implications for the new security imperative, homeland defense. Key technologies in nuclear and biological weapons, military platforms, and intelligence gathering. Policy issues from the point of view of U.S. and other nations. The impact of terrorist threat. Guest lecturers include key participants in the development of technology and/or policy. Students seeking to fulfill the WIM requirement should register for 193W.

*3 units, Aut (Perry, Paté-Cornell)*

**MS&E 193W. Technology and National Security**—(Same as 193/293.) Fulfills the WIM requirement. WIM

*3 units, Aut (Perry, Paté-Cornell)*

**MS&E 195. International Security in a Changing World**—(Enroll in POLISCI 114S.)

*5 units, Win (Sagan, Blacker, Perry)*

**MS&E 196. Transportation Systems and Urban Development**—(Graduate students register for 296.) Introduction to transportation systems and planning, and their roles in society. Analytical tools introduced at a conceptual level examine issues and evaluate alternatives. Policy implications and system effectiveness analysis of transportation in an urban context. Topics: economic analysis of transportation, supply and demand equilibrium analysis, urban transportation networks, congestion management, short and long term transportation planning, the impact of technology on transportation systems, land use and transportation, case studies and analysis of current transportation news items. Prerequisite: MATH 41.

*3 units (Chiu) not given 2004-05*

**MS&E 197. Ethics and Public Policy**—(Same as PUBLPOL 103B.) Ethical issues in science- and technology-related public policy conflicts. Goal is to develop rigorous critical analysis of complex, value-laden policy disputes. Topics: the natures of ethics and morality; the natures of and rationales for liberty, justice, and human rights; and the use and abuse of these concepts in recent and current policy disputes. Cases from biomedicine, environmental affairs, the technical professions, communications, and international relations. GER:3a,WIM

*5 units, Win (McGinn)*

## PRIMARILY FOR GRADUATE STUDENTS

### GENERAL AND SYSTEMS ANALYSIS METHODS

**MS&E 201. Dynamic Systems**—Goal is to think dynamically in decision making, and recognize and analyze dynamic phenomena in diverse situations. Concepts: formulation and analysis; state-space formulation; solutions of linear dynamic systems, equilibria, dynamic diagrams; eigenvalues and eigenvectors of linear systems, the concept of feedback; nonlinear dynamics, phase plane analysis, linearized analysis, Liapunov functions, catastrophe theory. Examples: grabber-holder dynamics, technology innovation dynamics, creation of new game dynamics in business competition, ecosystem dynamics, social dynamics, and stochastic exchange dynamics. Prerequisite: MATH 103 or equivalent.

*3-4 units, Spr (Tse)*

**MS&E 205. Aerospace Product and Systems Development**—(Enroll in AA 253.)

*3 units, Spr (Weiss)*

**MS&E 206. Art of Mathematical Modeling**—Practicum. Students build mathematical models of real-life, ill-framed problems. Emphasis is on framing the issues, articulating modeling components logically (drawing from student's mathematical background), and analyzing the resulting model. Hands-on modeling. Project work in small groups. Prerequisites: basic analysis, calculus and algebra, and probability theory. Recommended: decision analysis, optimization and dynamic systems.

*3-4 units, Spr, Sum (Kieffel)*

**MS&E 207. Interactive Management Science**—(Undergraduates register for 107; see 107.)

*3 units, Aut (Savage)*

**MS&E 208A,B,C. Practical Training**—Students obtain employment in a relevant industrial or research activity chosen to enhance their professional experience, and consistent with the degree program they are pursuing. Students must submit a one-page statement showing relevance to degree program along with offer letter before the start of the quarter, and a 2-3 page final report documenting the work done and relevance to degree program at the conclusion of the quarter. 1 unit counts toward the M.S. degree and 3 units toward the B.S. or Ph.D. degree. Prerequisite: MS&E student.

*1 unit, Aut, Win, Spr (Ye), Sum (Paté-Cornell)*

### OPTIMIZATION

**MS&E 211. Linear and Nonlinear Optimization**—The fundamental concepts of linear and nonlinear optimization theory and modeling. The role of prices, duality, and problem structure in finding and recognizing solutions. Perspectives: problem formulation, analytical theory, and computational methods. Theory: finite dimensional derivatives, convexity, optimality, duality, and sensitivity. Methods: simplex and variations, gradient, Newton, penalty, and barrier. Prerequisite: MATH 51.

*3-4 units, Aut (Staff)*

**MS&E 212. Mathematical Programming and Combinatorial Optimization**—(Undergraduates register for 112; same as CME 208.) Combinatorial and mathematical programming (integer and non-linear) techniques for optimization. Topics: linear program duality and LP solvers; integer programming; combinatorial optimization problems on networks including minimum spanning trees, shortest paths, and network flows; matching and assignment problems; dynamic programming; linear approximations to convex programs; NP-completeness. Hands-on exercises. Prerequisites: CS 106A or X; ENGR 62 or MATH 103. GER:2b

*3 units, Spr (Goel)*

## PROBABILITY AND STOCHASTIC SYSTEMS

**MS&E 220. Probabilistic Analysis**—Concepts and tools for analysis of problems under uncertainty, focusing on model building and communication: the structuring, processing, and presentation of probabilistic information. Examples from legal social, medical, and physical problems. Spreadsheets illustrate and solve problems as a complement to analytical closed-form solutions. Topics: axioms of probability, probability trees, random variables, distributions, conditioning, expectation, change of variables, and limit theorems. Prerequisite: MATH 51. Recommended: knowledge of spreadsheets.
*3-4 units, Aut (Shachter)*

**MS&E 221. Stochastic Modeling**—Continuation of 220. Topics: limit theorems, discrete and continuous time Markov chains, renewal processes, queuing theory, and transform analysis. Emphasis is on building a framework to formulate and analyze probabilistic systems. Prerequisite: 220 or consent of instructor.
*3 units, Win (Johari)*

**MS&E 223. Simulation**—Discrete-event systems, generation of uniform and non-uniform random numbers, Monte Carlo methods, programming techniques for simulation, statistical analysis of simulation output, efficiency-improvement techniques, decision making using simulation, applications to systems in computer science, engineering, finance, and operations research. Prerequisites: working knowledge of a programming language such as C, C++, Java, or FORTRAN; probability; and statistical methods.
*3 units, Spr (Haas)*

## INFORMATION SCIENCE AND TECHNOLOGY

**MS&E 230. Introduction to Computer Networks**—(Enroll in EE 284.)
*3-4 units, Aut (Tobagi)*

**MS&E 231. Information Systems**—(Undergraduates register for 130; see 130.)
*4 units, Aut (Goel)*

**MS&E 234. Organizations and Information Systems**—(Undergraduates register for 134; see 134.)
*4 units, Win (Tabrizi)*

**MS&E 236. Pricing Next Generation Telecommunications Products and Services**— Interdisciplinary. Position, price, and distribution of traditional and innovative telecommunication services. Topics: the telecommunication industry as driven by technological advances, policy choices, and business opportunities; the pricing revolution and arbitrage opportunities in international voice created by data-voice convergence and liberalization; competitive aspects of service delivery channels; commoditizing of bandwidth and basic services; clearinghouses; financial risk hedging through futures and derivatives trading; intelligent pricing and provisioning agents for product bundling; grade of service differentiation; positioning and revenue optimization by capturing consumer preferences. Group project in industrial participation.
*3 units, Sum (Chiu)*

**MS&E 237. Progress in Worldwide Telecommunications**—Interdisciplinary. Topics in current developments and economic trends. Prominent guest speakers. Topics include telecommunications services and networks, (de)regulation and market-driven competition, technology, standardization, international and regional organizations, and the needs of underserved parts of the world. Focus is on wireless communications, broadband user access, the Internet, and the impact of globalization. Individual or team case study and verbal presentation. May be repeated for credit. Limited enrollment.
*3 units, Sum (Ivanek, Chiu)*

## ECONOMICS, FINANCE, AND INVESTMENT

**MS&E 240. Industrial Accounting**—(Undergraduates register for 140; see 140.)
*3-4 units (Stanton)*

**MS&E 241. Economic Analysis**—Principal methods of the economic analysis of the production activities of firms (production technologies, cost and profit; perfect and imperfect competition); individual choice (preferences and demand); and the market-based system (price formation, efficiency, welfare.) Emphasis is on the analytical foundations and the practical applications of the methods presented. See 341 for continuation of 241. Recommended: 211, Economics 50.
*3-4 units, Win (Sweeney)*

**MS&E 242. Investment Science**—Theory and application of modern quantitative investment analysis. How investment concepts are used to evaluate and manage opportunities, portfolios, and investment products including stocks, bonds, mortgages, and annuities. Topics: deterministic cash flows (time-value of money, present value, internal rate of return, term structure of interest rates, bond portfolio immunization, project optimization); mean-variance theory (Markowitz model, capital asset pricing); and arbitrage pricing theory. Group project. Prerequisites: 120, ENGR 60, MATH 51, or equivalents. Recommended: 140, ENGR 62, knowledge of spreadsheets.
*3 units, Aut (Primbs)*

**MS&E 242S. Investment Science**—Emphasis is on a cash flow approach. Topics include deterministic cash flow analysis (time value of money, present value, internal rate of return, taxes, inflation), fixed income securities, duration and bond portfolio immunization, term structure of interest rates (spot rates, discount factors, forward rates), Fisher-Weill duration and immunization, capital budgeting, dynamic optimization problems, investments under uncertainty, mean-variance portfolio theory, capital asset pricing, and basic options theory. Goal is to create a link between engineering analysis and business decision making.
*3 units, Sum (Feinstein)*

**MS&E 243. Energy and Environmental Policy Analysis**—(Same as IPER 243.) Concepts, methods, and applications. Energy/environmental policy issues such as automobile fuel economy regulation, global climate change, research and development policy, and environmental benefit assessment. Group project. Prerequisite: 241 or ECON 50, 51.
*3 units, Spr (Goulder, Sweeney)*

**MS&E 245G. Finance I for Non-MBAs**—(Same as FINANCE 221, ECON 135.) For graduate students and advanced undergraduates. The foundations of finance with applications in corporate finance and investment management. Major financial decisions made by corporate managers and investors with focus on process valuation. Topics include criteria for investment decisions, valuation of financial assets and liabilities, relationships between risk and return, market efficiency, and the valuation of derivative securities. Major corporate financial instruments including debt, equity, and convertible securities. Limited enrollment. Prerequisites: ECON 51 or ENGR 60 or equivalent; ability to use spreadsheets, and basic probability and statistics concepts including random variables, expected value, variance, covariance, and simple estimation and regression.
*4 units, Win (Admati)*

**MS&E 247G. International Finance Management**—(Same as FINANCE 223/323.) A framework for making corporate financial decisions in an international context. Topics in international financial management. Focus is on the markets for spot exchange, currency forwards, options, swaps, international bonds, and international equities. For each of these markets, the valuation of instruments traded in these markets and, through cases, the application of these instruments to managing exposure to exchange rates, financing in international capital markets, and international capital budgeting.
*4 units, Spr (Staff)*

**MS&E 247S. International Investments**—Introduces international financial markets, their comparative behavior, and their interrelations. Focus is on the assets traded in liquid markets: currencies, equities, bonds, swaps, and derivatives. Topics: institutional arrangements, taxation and regulation, international arbitrage and parity conditions, valuation of target firms for cross-border acquisitions, direct foreign invest-

ment, international diversification and portfolio management, derivative instruments and dynamic investment strategies, international performance analysis, international capital flows and financial crises, and topics of current relevance and importance. Prerequisite: basic finance theory (equivalent of 242 or 245G).
*3 units, Sum (Fu)*

**MS&E 248. Economics of Natural Resources**—Intertemporal economic analysis of natural resource use, particularly energy, and including air, water, and other depletable mineral and biological resources. Emphasis is on an integrating theory for depletable and renewable resources. Stock-flow relationships; optimal choices over time; short- and long-run equilibrium conditions; depletion/extinction conditions; market failure mechanisms (common-property, public goods, discount rate distortions, rule-of-capture); policy options. Prerequisite: 241 or ECON 51.
*3-4 units, Aut (Sweeney)*

**MS&E 249. Growth and Development**—What generates economic growth. Emphasis is on theory accompanied by intuition, illustrated with country cases. Topics: the equation of motion of an economy; optimal growth theory; calculus of variations and optimal control approaches; deriving the Euler and Pontriaguine equations from economic reasoning. Applications: former planned economies in Russia and E. Europe; the financial crises in E. Asia and Argentina; a comparative study of India and China. The links between economic growth and civilization; the causes of the rise and decline of civilizations; lessons for the future.
*3 units, Sum (de La Grandville)*

## DECISION AND RISK ANALYSIS

**MS&E 250A. Engineering Risk Analysis**—The techniques of analysis of engineering systems for risk management decisions involving trade-offs (technical, human, environmental aspects). Elements of decision analysis; probabilistic risk analysis (fault trees, event trees); economic analysis of failure consequences (human safety and long-term economic discounting); and case studies (space, systems, nuclear power plants, liquefied natural gas terminals, and dams). Public and private sectors. Prerequisites: 120 or STATS 116, and ENGR 60, or equivalents.
*2-3 units, Win (Paté-Cornell)*

**MS&E 250B. Project Course in Engineering Risk Analysis**—Students, individually or in groups, choose, define, formulate, and resolve a real risk management problem, preferably from a local firm or institution. Oral presentation and report required. Scope of the project is adapted to the number of students involved. Three phases: risk assessment, communication, and management. Emphasis is on the use of probability for the treatment of uncertainties and sensitivity to problem boundaries. Limited enrollment. Prerequisite: 250A, consent of instructor.
*3 units, Spr (Paté-Cornell)*

**MS&E 251. Stochastic Decision Models**—Efficient formulation and computational solution of sequential decision problems under uncertainty. Markov decision chains and stochastic programming. Maximum expected present value and rate of return. Optimality of simple policies: myopic, linear, index, acceptance limit, and (s,S). Optimal stationary and periodic infinite-horizon policies. Applications to investment, options, overbooking, inventory, production, purchasing, selling, quality, repair, sequencing, queues, capacity, transportation. MATLAB is used. Prerequisites: probability, linear programming.
*3 units, Win (Veinott)*

**MS&E 252. Decision Analysis I**—Coherent approach to decision making, using the metaphor of developing a structured conversation having desirable properties, and producing actional thought that leads to clarity of action. Instruction is Socratic, with computational issues covered in problem sessions. Emphasis is on creation of distinctions, representation of uncertainty by probability, development of alternatives, specification of preference, and the role of these elements in creating a normative approach to decisions. Evaluates information gathering opportunities in terms of a value measure. Relevance and decision diagrams represent and clarify inference and decision. Principles are applied to decisions in business, technology, law, and medicine. See 352 for continuation.
*3-4 units, Aut (Howard)*

**MS&E 254. The Ethical Analyst**—The professional analyst who uses technical knowledge in support of any individual, organization, or government is ethically responsible for the consequences. Students are sensitized to ethical issues, providing the means to form ethical judgments, questioning the desirability of physical coercion and deception as a means to reach any end. Exploration of human action and relation in society in the light of previous thought, and additional research on the desired form of social interactions. Attitudes toward ethical dilemmas explored by creating an explicit personal code. Issues from the range of human affairs test the student's framework for ethical judgment.
*1-3 units, Spr (Howard)*

## PRODUCTION OPERATIONS, SERVICES, AND MANUFACTURING

**MS&E 260. Analysis of Production and Operating Systems**—(Undergraduates register for 160.) Businesses add value through production and delivery of products and services; operations managers are responsible for designing, running, and improving systems and processes to meet demand for goods and services. Techniques to analyze an operating system. Topics include determination of optimal facility location, production lot sizing, optimal timing and sizing of capacity expansion, and inventory control. Prerequisites: probability and optimization.
*4 units, Aut (Ozer)*

**MS&E 261. Inventory Control and Production Systems**—Topics in the planning and control of manufacturing systems. The functions of inventory, determination of order quantities and safety stocks, alternative inventory replenishment systems, item forecasting, production-inventory systems, materials requirements planning (MRP), just-in-time systems, master and operations scheduling, supply chain management, and service operations. Limited enrollment. Prerequisite: 120, or STATS 116, or equivalent.
*3 units, Win (Hausman)*

**MS&E 262. Supply Chain Management**—Definition of a supply chain; coordination difficulties; pitfalls and opportunities in supply chain management; inventory/service tradeoffs; performance measurement and incentives. Global supply chain management; mass customization; supplier management. Design and redesign of products and processes for supply chain management; tools for analysis; industrial applications; current industry initiatives. Enrollment limited to 50 MS&E students. Prerequisite: 260 or 261.
*3 units, Spr (Hausman)*

**MS&E 263. Internet-Enabled Supply Chains**—E-businesses have changed traditional supply chain interactions by creating a web-like structure and more flexible relationships, and it is no longer possible operationally or strategically to ignore the information-based virtual value chains for any business. How information technologies advanced supply chain integration; e-markets including auctions and exchanges; dynamic pricing; bundling; strategic implications of lock-in and switching costs; compatibility choices; and standardization efforts.
*3 units, Win (Erhun)*

**MS&E 264. Manufacturing Systems Design**—(Undergraduates register for 164.) Multidisciplinary. The concepts and techniques of designing and improving performance and productivity in systems composed of and influenced by people, organizational factors, environmental factors, and technology. Emphasis is on the design of high-performance manufacturing systems. Use of simulation as a tool for design evaluation.
*3 units, Aut (Erhun)*

**MS&E 265. Reengineering the Manufacturing Function**—Student teams redesign the manufacturing and distribution system of a medium-sized manufacturer. Focus is on the transportation system, inventory policies for a regional warehouse, design of a national distribution system, improvements of work flow, and layout of the manufacturing plant. The redesign is at a detailed operational level consistent with a strategy of integrating the functions of manufacturing and distribution. Analytical and game software is used. Knowledge of inventory theory, linear/integer programming, economic analysis, and applied probability is required. Emphasis is on group learning. Limited enrollment. Prerequisites: senior or graduate standing, 160, ENGR 60, and ENGR 62.

*4 units, Spr (Carlson) alternate years, not given 2005-06*

**MS&E 266. Management of New Product Development**—Techniques of managing or leading the process of new product development that have been found effective. Emphasis is placed on how much control is desirable and how that control can be exercised in a setting where creativity has traditionally played a larger role than discipline. Topics: design for manufacturability, assessing the market, imposing discipline on the new product development process, selecting the appropriate portfolio of new product development projects, disruptive technology, product development at internet speed, uncertainty in product development, role of experimentation in new product development, creating an effective development organization, and developing products to hit cost targets.

*3-4 units, Win (Carlson)*

**MS&E 267. Innovations in Manufacturing**—Emphasis is on forces that prompt change and their impact. Topics include changes in the mode of production, performance objectives, sources of inspiration, and work organization. Design and management implications for modern manufacturing.

*3-4 units, Aut (Bailey)*

**MS&E 268. Manufacturing Strategy**—The development and implementation of the manufacturing functional strategy. Emphasis is on the integration of manufacturing strategy with the business and corporate strategies of a manufacturing-based firm. Topics: types of manufacturing technologies and their characteristics, quality management, capacity planning and facilities choice, the organization and control of operations, and determining manufacturing's role in corporate strategy. Prerequisites: graduate student; 260 or 261.

*3 units, Spr (Carlson)*

**MS&E 269. Quality Engineering: Qualitative Concepts and Statistical Analysis**—(Undergraduates register for 169.) Topics include the cost of quality, statistical process control, inspection, sampling plans, uncertainty in the supply process, Bayesian decision methods, reliability, robust quality, quality function deployment, engineering aspects of product liability, and the design of experiments. Case studies. Class project involving local industry required for fourth unit. Prerequisites: 120, and STATS 110.

*3-4 units, Win (Brandeau)*

## STRATEGY, ENTREPRENEURSHIP, AND MARKETING

**MS&E 270. Strategy in Technology-Based Companies**—For graduate students only. Introduction to the basic concepts of strategy, with emphasis on high technology firms. Topics: competitive positioning, resource-based perspectives, co-opetition and standards setting, and complexity/evolutionary perspectives. Limited enrollment.

*3-4 units, Aut (Eisenhardt), Win (Katila)*

**MS&E 271. Global Entrepreneurial Marketing**—Designed to equip engineers with the marketing skills needed to launch and lead a high growth, high-tech venture, market new products to new customers, and use new technology in startups and global high tech firms. Case method, working in teams. Students diagnose problems and opportunities, make decisions, and analyze customers, competitors, channels, and their own company, while testing their recommended approach. Economic environments and ethical factors that affect decisions. Strategic paper required. Limited enrollment.

*4 units, Win, Spr (Kosnik)*

**MS&E 272. Entrepreneurial Finance**—Primarily for graduate engineering students. Introduction to the concepts in and around the financing of entrepreneurial companies. Focus is on teaching future general managers how to use financial perspective to make better decisions in entrepreneurial settings, including selecting financial partners, evaluating financing vehicles, and financing companies through all growth stages, from startup through initial public offering. Limited enrollment. Prerequisites: 140, and ENGR 60. Recommended: 245G.

*3 units, Spr (MacKenzie)*

**MS&E 273. Technology Venture Formation**—Open to graduate students interested in high-technology entrepreneurship. Explores in detail the process of starting venture scale high-tech businesses. Coursework includes assessing opportunities, sizing markets, evaluating sales channels, developing R&D and operations plans, raising venture capital, managing legal issues, and building a team. The teaching team includes experienced entrepreneurs, venture capitalists, and distinguished guests. Student teams write a business plan and make a formal presentation to group of first tier venture capitalists. Enrollment limited. Recommended: 140, 270, 271, 272 or equivalent.

*3-4 units, Aut (Lyons, MacLean, Leslie)*

**MS&E 274. Building Dynamic Entrepreneurial Organizations**—Focus is on the dynamic development of corporate skills, knowledge, and infrastructure to compete in a changing global competitive environment due to rapid technology advancement, global economic development, changes in consumer's preference, and government regulations. Model analysis and case studies are used to develop a methodology in building dynamic entrepreneurial organizations in response to dynamic competitive requirements. Links between MS&E core and the notion of managing change as a basis for a normative theory on entrepreneurial activities in new business creation and corporate expansion.

*3 units, Win (Tse)*

**MS&E 277. Creativity and Innovation**—Focus is on factors that promote and inhibit creativity of individuals, teams, and organizations. Creativity tools, assessment metrics, and exercises; workshops, field trips, and case studies. Each student completes an individual creativity portfolio and participates in a long-term team project. Enrollment limited to 40. See http://creativity.stanford.edu.

*4 units, Spr (Seelig)*

**MS&E 278. Startup Globalization Strategies**—(Same as GSBGEN 354.) Approaches to the global marketplace adopted by startups and how they are employed in different industries and continents.

*4 units, Spr (Foster)*

## ORGANIZATIONAL BEHAVIOR, MANAGEMENT, AND WORK

**MS&E 280. Organizational Behavior and Management**—Organization theory; concepts and functions of management; behavior of the individual, work group, and organization. Emphasis is on case and related discussion. Enrollment limited to 65 graduate students per section; priority to MS&E majors.

*3-4 units, Win (Sutton)*

**MS&E 281. Management and Organization of Research and Development**—The organization of R&D in industry and the problems of the technical labor force. Relevant theoretical perspectives from sociology, anthropology, and management theory on the social and pragmatic issues that surround technical innovation and the employment of scientists and engineers. Possible topics: organization of scientific and technical communities, industrialization of research, the nature of scientific and technical work, strategies for fostering innovation, careers of scientists and engineers, and managerial problems characteristic of R&D settings.

*3 units, Win (Barley)*

**MS&E 284. Technology and Work**—Theory and research on the social implications of technology and technological change for workers at all levels. Alternate conceptions of technology as social phenomenon, approaches to the study of technology in the workplace, reactions of individuals and groups to technological change, the construction of a technology's social meaning, and the management of technological change. Emphasis is on automation, electronic data processing, and sophisticated microelectronic technologies, including CAD-CAM systems, telecommunication networks, medical imaging technologies, artificial intelligence, and personal computers.

*3 units (Barley) alternate years, given 2005-06*

**MS&E 285. Negotiation**—(Same as CEE 151/251, ME 207.) Introduction to negotiation styles and processes in order to help students conduct and review negotiations. Workshop format integrating intellectual and experiential learning. Students analyze the negotiation process through exercises, live and field examples, individual and small group reviews. Students must apply before the first day of class. See course website for details. Enrollment limited to 50.

3 units, Aut, Spr *(Christensen)*

### PUBLIC POLICY ANALYSIS

**MS&E 290. Public Policy Analysis**—Focus is on national security, health/medical, technology regulation/intellectual property rights, and energy/environment. Each student writes a short policy analysis brief in each of the four areas.

*3 units, Win (Weyant, Perry, Shachter, North)*

**MS&E 292. Health Policy Modeling**—This Master's level course is on the application of mathematical, statistical, economic, and systems models to problems in health policy. Areas covered include disease screening, prevention, and treatment; assessment of new technologies; and drug control policies.

*3 units, Win (Brandeau)*

**MS&E 293. Technology and National Security**—(Undergraduates register for 193; see 193.)

*3 units, Aut (Perry, Paté-Cornell)*

**MS&E 294. Climate Policy Analysis**—Design and application of formal analytical methods in climate policy development. Issues include instrument design, technology development, resource management, multiparty negotiation, and dealing with complexity and uncertainty. Links among art, theory, and practice. Emphasis is on integrated use of modeling tools from diverse methodologies and requirements for policy making application. Recommended: background in economics, optimization, and decision analysis.

*3 units, Win (Weyant)*

**MS&E 296. Transportation Systems and Urban Development**—(Undergraduates register for 196; see 196.)

*3 units (Chiu) not given 2004-05*

**MS&E 298. Technology, Policy, and Management in Newly-Industrializing Countries**—(Enroll in STS 279.)

*2-4 units, Aut (Forbes)*

**MS&E 299. Voluntary Social Systems**—Exploration of ethical theory, feasibility, and desirability of a social order in which coercion by individuals and government is minimized and people pursue ends on a voluntary basis. Topics: efficacy and ethics; use rights for property; contracts and torts; spontaneous order and free markets; crime and punishment based on restitution; guardian-ward theory for dealing with incompetents; the effects of state action-hypothesis of reverse results; applications to help for the needy, armed intervention, victimless crimes, and environmental protection; transition strategies to a voluntary society.

*1-3 units, Win (Howard)*

## PRIMARILY FOR DOCTORAL STUDENTS

### GENERAL AND SYSTEMS ANALYSIS METHODS

**MS&E 300. Ph.D. Qualifying Tutorial or Paper**—Restricted to Ph.D. students assigned tutorials as part of the MS&E Ph.D. qualifying process. Enrollment optional.

*1-3 units, Aut, Win, Spr, Sum (Staff)*

**MS&E 301. Dissertation Research**—Prerequisite: doctoral candidacy.

*1-15 units, Aut, Win, Spr, Sum (Staff)*

**MS&E 303. Readings in Decomposition Principles**—For Ph.D. students interested in modeling and solving large optimization problems. Focus is on structure and solution principles rather than detailed algorithms. Topics include Dantzig-Wolfe and Benders' decomposition principles and their duality relationship, decomposition and solving large Markov chains, decomposition and incentive compatibility, and applications of decomposition principles to solving large problems. Master's students require consent of instructor. Prerequisites: 211, 220. Recommended: Markov chains.

*1-3 units, Spr (Chiu)*

### OPTIMIZATION

**MS&E 310. Linear Programming**—Formulation of standard linear programming models. Theory of polyhedral convex sets, linear inequalities, alternative theorems, and duality. Variants of the simplex method and the state of art interior-point algorithms. Sensitivity analyses, economic interpretations, and primal-dual methods. Relaxations of harder optimization problems and recent convex conic linear programs. Applications include game equilibrium facility location. Prerequisite: MATH 113 or consent of instructor.

*3 units, Aut (Ye)*

**MS&E 311. Optimization**—Applications, theory, and algorithms for finite-dimensional linear and nonlinear optimization problems with continuous variables. Elements of convex analysis, first- and second-order optimality conditions, sensitivity and duality. Algorithms for unconstrained optimization, linearly constrained optimization problems (including linear and quadratic programs), and nonlinearly constrained problems. Prerequisites: MATH 113, 115, or equivalent.

*3 units, Win (Ye)*

**MS&E 312. Advanced Methods in Numerical Optimization**—(Same as CME 334.) Topics include interior-point methods, relaxation methods for nonlinear discrete optimization, sequential quadratic programming methods, and decomposition methods. Topic chosen in first class.

*3 units, Aut (Murray)*

**MS&E 313. Vector Space Optimization**—Optimization theory from the unified framework of vector space theory, treating together problems of mathematical programming, calculus of variations, optimal control, estimation, and other optimization problems. Emphasizes geometric interpretation. Duality theory. Examples. Topics: vector spaces, including function spaces; Hilbert space and the projection theorem; dual spaces and the separating hyperplane theorem; linear operators and adjoints; optimization of functionals including theory of necessary conditions in general spaces, and convex optimization theory; constrained optimization, including Fenchel duality theory. Prerequisite: MATH 115.

*3 units, Aut (Luenberger) alternate years, not given 2005-06*

**MS&E 314. Linear and Conic Optimization with Applications**—(Same as CME 336.) Linear, semidefinite, conic, and convex nonlinear optimization problems as generalizations of classical linear programming. Algorithms include the simplex method, interior-point methods, barrier function methods, cutting plane methods. Related convex analysis, including the separating hyperplane theorem, Farkas lemma, dual cones, optimality conditions, and conic inequalities. Complexity and/or computation efficiency analysis. Applications to max-cut problems, Markov chain mixing times, support vector machines for data mining and classification, graph partitioning, robust portfolio selection, and Euclidian distance geometry. Prerequisite: MS&E 211, or equivalent.

*3 units, Spr (Ye)*

**MS&E 315. Numerical Optimization**—(Same as CME 304.) Solution of nonlinear equations; unconstrained optimization; linear programming; quadratic programming; global optimization; general linearly constrained optimization. Theory and algorithms to solve these problems. Prerequisite: background in analysis and numerical linear algebra.

*3 units, Win (Murray)*

**MS&E 317. Advanced Combinatorial Optimization**—Combinatorial and algorithmic techniques for optimization problems. Emphasis is on algorithms with provable correctness and efficiency. Topics include network flows, Gomory-Hu decompositions, maximum matchings, stable marriages, matroids and submodular function optimization, Vizing's theorem and edge colorings, small-separator graphs, and packings of directed trees. Applications to real-life problems and connections to other branches of optimization and mathematics. Prerequisites: 212 or CS 261 or equivalent.
*3 units (Goel) alternate years, given 2005-06*

**MS&E 318. Large-Scale Numerical Optimization**—(Same as CME 338.) The main algorithms for general constrained optimization emphasizing the sparse-matrix techniques required for their implementation. Sparse factorizations and updating. Iterative methods for linear equations and least squares. Their use in simplex, reduced-gradient, SQP, LCL, and interior methods. Software implementing such methods. Prerequisites: linear algebra and optimization. Recommended: MS&E 310, 311, 312, 314 or 315; CS 137 or 237A.
*3 units, Spr (Saunders)*

**MS&E 319. Approximation Algorithms for Optimization Problems**—Combinatorial and mathematical programming techniques to derive approximation algorithms for NP-hard optimization problems. Possible topics include: greedy algorithms for vertex/set cover; tree-based approximations; approximation schemes via dynamic programming; rounding LP relaxations of integer programs; semidefinite relaxations; geometric embeddings; resource augmentation; simultaneous optimization. May be repeated for credit. Prerequisites: 112 or CS 161.
*3 units, Win (Goel)*

### PROBABILITY AND STOCHASTIC SYSTEMS

**MS&E 321. Stochastic Systems**—Topics in stochastic processes, emphasizing applications. Markov chains in discrete and continuous time; Markov processes in general state space; Lyapunov functions; regenerative process theory; renewal theory; martingales, Brownian motion, and diffusion processes. Application to queueing theory, storage theory, reliability, and finance. Prerequisites: 221 or STATS 217; MATH 113, 115.
*3 units, Spr (Glynn)*

**MS&E 322. Stochastic Calculus and Control**—Ito integral, existence and uniqueness of solutions of stochastic differential equations (SDEs), diffusion approximations, numerical solutions of SDEs, controlled diffusions and the Hamilton-Jacobi-Bellman equation, and statistical inference of SDEs. Applications to finance and queueing theory. Prerequisites: 221 or STATS 217: MATH 113, 115.
*3 units (Glynn) alternate years, given 2005-06*

**MS&E 323. Stochastic Simulation**—Emphasis is on the theoretical foundations of simulation methodology. Generation of uniform and non-uniform random variables. Discrete-event simulation and generalized semi-Markov processes. Output analysis (autoregressive, regenerative, spectral, and stationary times series methods). Variance reduction techniques (antithetic variables, common random numbers, control variables, discrete-time, conversion, importance sampling). Stochastic optimization (likelihood ratio method, perturbation analysis, stochastic approximation). Simulation in a parallel environment. Prerequisite: MS&E 221 or equivalent.
*3 units, Win (Glynn) alternate years, not given 2005-06*

### INFORMATION SCIENCE AND TECHNOLOGY

**MS&E 334. Network Architectures and Performance Engineering**—(Enroll in EE 384S.)
*3 units, Spr (Bambos)*

**MS&E 335. Queuing Systems and Networks**—Advanced stochastic modeling and analysis of systems involving queuing delays. Markovian queues. Stability analysis of the G/G/1 queue. Key results on single and multi-server queues. Approximation methods. Queuing networks. Introduction to controlled queuing systems. Applications to performance modeling, analysis, and evaluation of communication networks, computer systems, flexible manufacturing systems, service systems, etc. Prerequisite: 221 or equivalent.
*3 units, Aut (Bambos)*

**MS&E 336. Market Models for Network Resource Allocation**—Recent applications of economics to engineering problems in network resource allocation. Topics: network resource allocation problems and network market models. Equilibirum notions: Walrasian, Nash, Bayesian, and dominant strategy. Implementation theory: market clearing mechanisms, cost sharing mechanisms, Groves mechanisms, and welfare properties. Dynamics and algorithms. Elements of market and game theory, and additional research topics as time permits. Prerequisite: 211 or equivalent.
*3 units, Aut (Johari)*

**MS&E 338. Advanced Topics in Information Science and Technology**—Advanced material is sometimes taught for the first time as a topics course. Prerequisite: consent of instructor.
*3 units, Aut (Van Roy)*

**MS&E 339. Approximate Dynamic Programming**—Approximation algorithms for large-scale dynamic programming. Real-time dynamic programming and reinforcement learning algorithms. Generalizations of value iteration, policy iteration, and linear programming approaches. Recent research topics on approximate dynamic programming. Prerequisite: 251, 351, CS 221, CS 228, or CS 229.
*3 units, Win (Van Roy)*

### ECONOMICS, FINANCE, AND INVESTMENT

**MS&E 341. Advanced Economic Analysis**—Builds on 241 concepts. Market structure and industrial organization (oligopoly, strategic behavior of firms, game theoretic models); economics of uncertainty; general equilibrium theory and economic efficiency (formulation, Walras' Law, existence, uniqueness, duality between efficiency and general equilibrium; trade); intertemporal equilibrium and asset markets; public goods, externalities. Background for additional advanced economics. Prerequisite: 241.
*3 units, Spr (Weber)*

**MS&E 342. Advanced Investment Science**—Topics: forwards and futures contracts, continuous and discrete time models of stock price behavior, geometric Brownian motion, Ito's lemma, basic options theory, Black-Scholes equation, advanced options techniques, models and applications of stochastic interest rate processes, and optimal portfolio growth. Computational issues and general theory. Teams work on independent projects. Prerequisite: 242.
*3 units, Win (Luenberger)*

**MS&E 344. Applied Information Economics**—The strategic acquisition, pricing, transfer, and use of information. Theoretical findings applied to real-world settings. Topics: optimal risk bearing, adverse selection, signaling, screening, nonlinear and state-contingent pricing, design of contests, incentives and organizations, strategic information transmission, long-run relationships, negative information value, research and invention, leakage and espionage, imperfect competition, information sharing, search and advertising, learning, and real-option exercise games. Prerequisites: 211, 220, 241. Recommended: 341.
*3 units, Win (Weber)*

**MS&E 345. Advanced Topics in Financial Engineering**—Advanced modeling of assets for derivative pricing. Pricing and hedging of derivative securities, including exotic options and other structured securities. Risk management and analysis of portfolios with derivative securities. Greek analysis and analytic and numerical Value at Risk computation for static and dynamic portfolios. Prerequisites: 242, 220, 221, 342, or consent of instructor.
*3 units, Win (Primbs)*

**MS&E 346. Economic Analysis of Market Organizations**—For second-year or more advanced graduate students. Applies theories of microeconomics and management science to strategic behavior and mechanism design in market organizations, emphasizing incentives and asymmetric information structures. Topics: economics of information, nonlinear pricing, contracting, auction, bargaining, and market design in network infrastructure industries. Prerequisites: microeconomics, optimization, and decision or game theory.

*3 units, Win (Chao)*

**MS&E 348. Optimization of Uncertainty and Applications in Finance**—How to make optimal decisions in the presence of uncertainty, solution techniques for large-scale systems resulting from decision problems under uncertainty, and applications in finance. Decision trees, utility, two-stage and multi-stage decision problems, approaches to stochastic programming, model formulation; large-scale systems, Benders and Dantzig-Wolfe decomposition, Monte Carlo sampling and variance reduction techniques, risk management, portfolio optimization, asset-liability management, mortgage finance. Projects involving the practical application of optimization under uncertainty to financial planning.

*3 units, Win (Infanger)*

**MS&E 349. Investment Science Frontiers**—Advanced concepts of investment science with emphasis on theories and methods for solving practical problems: real options theory and practice; valuing and structuring projects, mergers, acquisition and contracts; designing portfolios for optimal growth; and managing risk and enhancing value within a complex business enterprise. Combination lecture, seminar, and project. No auditors. Prerequisites: 242, 342.

*3 units (Luenberger) not given 2004-05*

## DECISION AND RISK ANALYSIS

**MS&E 350. Doctoral Seminar in Risk Analysis**—Limited to doctoral students. Reading/review of the literature in the fields of engineering risk assessment and management. New methods and topics, emphasizing probabilistic methods and decision analysis. Applications to risk management problems involving the technical, economic, and organizational aspects of engineering system safety. Possible topics: treatment of uncertainties, learning from near misses, and use of expert opinions.

*3 units (Paté-Cornell) not given 2004-05*

**MS&E 351. Dynamic Programming and Stochastic Control**—Markov population decision chains in discrete and continuous time. Risk posture. Present value and Cesaro overtaking optimality. Optimal stopping. Successive approximation, policy improvement, and linear programming methods. Team decisions and stochastic programs; quadratic costs and certainty equivalents. Maximum principle. Controlled diffusions. Examples from inventory, overbooking, options, investment, queues, reliability, quality, capacity, transportation. MATLAB. Prerequisites: MATH 113, 115; Markov chains; linear programming.

*3 units, Spr (Veinott)*

**MS&E 352. Decision Analysis II**—Necessary considerations to assist people and organizations in decision making: decision engineering. How to organize the decision conversation, the role of the decision analysis cycle and the model sequence, assessing the quality of decisions, framing decisions, the decision hierarchy, strategy tables for alternative development, creating spare and effective decision diagrams, biases in assessment, knowledge maps, uncertainty about probability. Sensitivity analysis, approximations, value of revelation, joint information, options, flexibility, bidding, assessing and using corporate risk attitude, risk sharing and scaling, and decisions involving health and safety. See 353 for continuation. Prerequisite: 252

*3-4 units, Win (Howard)*

**MS&E 353. Decision Analysis III**—Extending the boundaries of systematic analysis of decisions. The concept of decision composite; probabilistic insurance and other challenges to the normative approach; the relationship of decision analysis to classical inference and data analysis procedures; the likelihood and exchangeability principles; inference, decision, and experimentation using conjugate distributions; developing a risk attitude based on general properties; alternative decision aiding practices such as analytic hierarchy and fuzzy approaches. Students presentations on current research. Goal is to prepare doctoral students for research. Prerequisite: 352.

*3 units, Spr (Howard)*

**MS&E 355. Influence Diagrams and Probabilistics Networks**—Network representations for reasoning under uncertainty: influence diagrams, belief networks, and Markov networks. Structuring and assessment of decision problems under uncertainty. Learning from evidence. Conditional independence and requisite information. Node reductions. Belief propagation and revision. Simulation. Linear-quadratic-Gaussian decision models and Kalman filters. Dynamic processes. Bayesian meta-analysis. Prerequisites: 220, 252, or equivalents; or consent of the instructor.

*3 units (Shachter) not given 2004-05*

## PRODUCTION OPERATIONS, SERVICES, AND MANUFACTURING

**MS&E 361. Supply-Chain Optimization**—Characterization and computation of optimal and nearly optimal multiperiod supply chain policies with known or uncertain demands using dynamic, lattice, network, and convex and concave programming. Cooperation: sharing benefits of alliances. Competition. Leontief-substitution and network-flow models. Lattice programming: comparison of optima; existence and comparison of equilibria of non-cooperative games. Stochastic comparison. Invariant properties of optimal flows: graphical optimization of supply chains. Optimality of myopic policies. Prerequisites: MATH 115, optimization theory, probability.

*3 units (Veinott) alternate years, given 2005-06*

**MS&E 362. Advanced Models in Production and Operations**—The design and operation of production-inventory systems. Topics include production scheduling, capacity planning, sequencing, assembly-line balancing, dynamic scheduling, and multigoal optimizations. Readings primarily from journal articles. Prerequisite: 260.

*3 units (Carlson) alternate years, given 2005-06*

**MS&E 363. Advanced Models in Management Science**—Primarily for doctoral students. Content varies. Topics based on recent literature and working papers. See http://www.stanford.edu/~ozalp/ for information. Prerequisite: consent of instructor.

*3 units, Aut (Ozer) alternate years, not given 2005-06*

**MS&E 364. Single and Multi-Location Inventory Models**—Theoretical treatment of control problems arising in inventory management, production, and distribution systems. Periodic and continues review inventory control for single and multi-location systems. Emphasis is on operating characteristics, performance measures, and optimal operating and control policies. Introduction to dynamic programming and applications in inventory control. Prerequisite: STATS 217 or equivalent, linear programming.

*3 units (Ozer) alternate years, given 2005-06*

**MS&E 365. Game Theoretic Models in Operations Management**—Formal analysis of the strategic interactions between multiple decision makers, such as suppliers, manufacturers, retailers,and consumers; resulting dynamics in a market environment. Game theory as the main tool of analysis. Readings primarily from journal articles.

*3 units, Win (Erhun) alternate years, not given 2005-06*

**MS&E 369. Supply Chain Risk and Flexibility Management**—Methods and analytic tools for quantifying and managing the impact of uncertainty in supply and demand on the operating and financial performance of firms and networks of firms. Design and delivery of products and services to provide competitive differentiation by enabling cost, value, risk, and flexibility to be balanced and managed across supply networks. Case study applications by leading companies to procurement, manufacturing, outsourcing, and sales relationships. Tools, processes, and internal crossfunctional coordination required to operationalize approaches in core planning and execution systems and processes. Prerequisite: 262.

*3 units, Aut (Johnson)*

## STRATEGY, ENTREPRENEURSHIP, AND MARKETING

**MS&E 371. Innovation and Strategic Change**—Doctoral research seminar. Current research on innovation strategy. Topics: scientific discovery, innovation search, organizational learning, evolutionary approaches, and incremental and radical change. Topics change yearly. Recommended: course in statistics or research methods. Enrollment limited to Ph.D. students.

*2-3 units (Katila) not given 2004-05*

**MS&E 374. Dynamic Corporate Strategy**—Enrollment limited to Ph.D. students. Research on the creation and shaping of disruptive industry dynamics and how companies can formulate and implement strategies to excel in such changing environments. Dynamic system model approach; case studies. Prerequisites: 201 or equivalent, 274.

*3 units, Win (Tse)*

**MS&E 376. Strategy and Organization Doctoral Research Seminar**—Current research at the interface between strategy policy and organization theory. Topics vary annually. Limited enrollment. Prerequisites: SOC 360 or equivalent, and consent of instructor.

*3 units, Aut (Eisenhardt)*

## ORGANIZATIONAL BEHAVIOR, MANAGEMENT, AND WORK

**MS&E 380. Doctoral Research Seminar in Organizations**—Limited to Ph.D. students. Topics from current published literature and working papers. Content varies. Prerequisite: consent of instructor.

*3 units, Spr (Sutton)*

**MS&E 381. Doctoral Research Seminar in Work, Technology, and Organization**—Enrollment limited to Ph.D. students. Topics from current published literature and working papers. Content varies. Prerequisite: consent of instructor.

*2-3 units, Aut (Barley)*

**MS&E 383. Doctoral Seminar on Ethnographic Research**—For graduate students; upper-level undergraduates with consent of instructor. Ethnosemantic interviewing and participant observation. Techniques for taking, managing, and analyzing field notes and other qualitative data. 15 hours per week outside class collecting and analyzing own data. Methods texts and ethnographies offer examples of how to analyze and communicate ethnographic data. Prerequisite: consent of instructor.

*5-6 units (Barley) alternate years, given 2005-06*

**MS&E 384. Groups and Teams**—Topics such as group effectiveness, norms and roles, diversity, cohesion and conflict, learning, and distributed teams. Boundary spanning and intergroup relations.

*3 units, Win (Hinds)*

**MS&E 385. Geographically Distributed Work**—Focus is on understanding how being distributed from one's coworkers can affect productivity, interpersonal relationships, perceptions of work, information sharing, organizational structure, and other factors related to work and work effectiveness. Current research on distributed work and research in related areas that provide a theoretical foundation for understanding the impact of distance on work. Prerequisite: consent of instructor.

*1-3 units (Hinds) not given 2004-05*

## PROJECT COURSES, SEMINARS, AND WORKSHOPS

**MS&E 408. Directed Reading and Research**—Directed study and research on a subject of mutual interest to student and faculty member. Prerequisite: faculty sponsor.

*1-15 units, Aut, Win, Spr, Sum (Staff)*

**MS&E 412. Affiliate Project Course**—Students work on a project with an MS&E Department Affiliate Company. Projects not necessarily available every year. Prerequisite: consent of instructor.

*3-4 units, Win (Savage)*

**MS&E 430. Contextual and Organizational Issues in Human-Computer Interaction**—(Same as CS 247B.) Focus is on the contextual issues associated with designing and using computer interfaces and technology, providing insights into, experience with, and ways of understanding issues in work and consumer settings that influence the design of computer interfaces. Student team projects develop skills in: observing individuals and groups of people in context, using models of work and other activity to extend their design capabilities, identifying constraints and tradeoffs on designs within the context of use, and observing and working with people in interdisciplinary design groups. Enrollment limited. Prerequisite: 247A; those whose program of study is closely related to HCI admitted, space permitting.

*3-4 units, Spr (Hinds)*

**MS&E 444. Investment Practice**—Projects enhance the student's abilities to formulate and design superior solutions to financial issues in industry and the financial services sector. Short projects illustrate the basic application and implementation of investment principles. Students complete a new project from industry. Enrollment limited to 30 MS&E students. Prerequisites: 242, 342.

*3-4 units, Spr (R. Luenberger)*

**MS&E 446. Policy and Economics Research Roundtable (PERR)**—Presentations and discussions of research in progress or contemplated, in policy and economics areas. Students present either their own research or, subject to approval, recent research by others. Particular emphasis depends on research interests of participating students, but is likely to include energy, environment, transportation, or technology policy and analysis.

*1 unit, Aut, Win, Spr (Sweeney)*

**MS&E 451. Decision Systems I: Professional Secrets and Tricks of the Trade**—Professional tricks for designing decision systems that help many decision makers who face similar decisions such as buying a car, bidding on the internet, hiring NFL players, making charitable donations, or selecting medical treatment. Lectures, demonstrations, and small project. Key topics: automatic decision diagram formulation, decision-class analysis, and dynamic sensitivity analysis. No programming required.

*2 units, Win (Holtzman, Robinson)*

**MS&E 452. Decision Systems II: Business, Consumer, and Medical Applications**—Students design a system to help business, consumer, medical, or other decision makers. Previous student teams have designed systems for auction bidding, cancer treatment, sailing tactics, automobile purchasing, network design, Mars exploration, flu treatment, platoon tactics, high-tech manufacturing, and oil-and-gas exploration. No programming required. Satisfies MS&E project course requirement. Prerequisite: 252 or equivalent. Recommended: 451.

*3 units, Spr (Holtzman, Robinson)*

**MS&E 454. Decision Analysis Seminar**—Current research and related topics presented by doctoral students and invited speakers.

*1 unit, Aut, Win, Spr (Howard)*

**MS&E 455. Decision Making in Organizations: The Right People and Process**—Lectures and war stories from management consultants experienced in applying decision analysis. Student teams critique decisions from news articles, case studies, and interviews with leaders of local organizations. Topics: roles people play, normative versus descriptive processes, decision quality measures, avoiding traps and failure modes, creativity, decision psychology, leadership profiles, organizational structure and defenses, efficient value creation, rewarding decisions, HDTV R&D analysis, the C5 Corvette design decision, and movie studio portfolio evaluations.

*2 units, Aut (Robinson, Holtzman)*

**MS&E 456. Decision Making Models and Methods: The Right Structure and Analysis**—Experienced management consultants show how to use decision analysis in real situations. Quantitative tools and techniques for modeling dynamics, uncertainty, and complexity. Decision hierarchies and strategy tables identify what choices and alternatives are possible. Decision diagrams and probability assessments capture complexity and document what is known and not known. Preference models describe what is desired. Sensitivity and information analysis focus attention on what is key. Student teams apply models and methods in actual decisions.
*2 units, Win (Robinson, Holtzman)*

**MS&E 457. Decision Analysis Projects: Practice and Applications**—A virtual consulting firm directed by experienced management consultants. Student teams help local organizations with decisions such as new business start-up, R&D portfolio investment, new product and market selection, strategic focus and direction, cost and staff reduction, and public policy optimization. Typical organizations include businesses, non-profits, healthcare providers, government entities, and educational institutions. Emphasis is on delivering insights and clarity of action to clients. Satisfies MS&E project course requirement. Prerequisite: 252 or equivalent.
*3 units, Spr (Robinson, Holtzman)*

**MS&E 458. Professional Decision Consulting: Selling Services, Managing Projects, Delivering Results**—Experienced management consultants share their top ten lessons they have learned about marketing and sales of professional services, pricing to value, leading and managing consulting projects, communicating decision insights to diverse audiences, and delivering clear results that exceed client expectations. What it looks like from inside a consulting firm, from the client's view, and from the consulting industry perspective. Student teams develop answers to frequently asked questions, prepare marketing materials, and present proposals for consulting services to decision makers in local organizations.
*2 units, Aut (Robinson, Holtzman)*

**MS&E 459. Interdisciplinary Seminar on Conflict and Dispute Resolution**—(Same as LAW 611, PSYCH 283.) Problems of conflict resolution and negotiation from an interdisciplinary perspective. Presentations by faculty and scholars from other universities.
*1 unit, Win (Hensler, Ross)*

**MS&E 464. Global Project Coordination**—Students engage in projects that are global in nature, and related to the planning and design of supply chains, marketing, manufacturing, and product development. Project teams from Stanford and an overseas university work on common projects using telephones, faxes, email, Internet, video conferencing, and face-to-face meetings. As part of the project, students travel to Hong Kong or the Netherlands. Applications due in November for Winter, and February for Spring.
*3-4 units, Win (Tabrizi), Spr (Peleg)*

**MS&E 472. Entrepreneurial Thought Leaders' Seminar**—Entrepreneurial leaders share lessons from real-world experiences across entrepreneurial settings. ETL speakers include entrepreneurs, leaders from global technology companies, venture capitalists, and best-selling authors. Half-hour talks followed by half hour of class interaction. Required web discussion. May be repeated for credit.
*1 unit, Aut, Win, Spr (Byers, Kosnik, Seelig)*

**MS&E 474. Business and Environmental Issues**—(Same as GES 203.)
*1-2 units, Spr (Sweeney, Matson)*

**MS&E 478. Topics in International Technology Management**—(Enroll in EE 402A.)
*1 unit, Aut (Dasher)*

**MS&E 479. Entrepreneurship in Asian High Tech Industries**—(Enroll in EE 402T.)
*1 unit, Spr (Dasher)*

# MATERIALS SCIENCE AND ENGINEERING

*Emeriti: (Professors)* Clayton W. Bates, Jr., Richard H. Bube, Theodore H. Geballe,* Stig B. Hagstrom,* Robert A. Huggins, William D. Nix,* Oleg D. Sherby, John C. Shyne, William A. Tiller, Robert L. White*
*Professor (Research)* Robert S. Feigelson*
*Chair:* Bruce M. Clemens
*Associate Chair:* Reinhold H. Dauskardt
*Professors:* David M. Barnett, Arthur I. Bienenstock, John C. Bravman, Bruce M. Clemens, Reinhold H. Dauskardt, Friedrich B. Prinz, Robert Sinclair
*Associate Professors:* Paul C. McIntyre, Shan X. Wang
*Assistant Professors:* Mark L. Brongersma, Michael D. McGehee, Nicholas Melosh
*Courtesy Professors:* Curtis W. Frank, James S. Harris, James D. Plummer, Jonathan F. Stebbins, Joachim Stohr
*Courtesy Associate Professor:* Stacey Bent
*Courtesy Assistant Professors:* Kyeongjae Cho, Ian Fisher, Harindran Manoharan
*Consulting Professors:* Paul A. Flinn, Timur Halicioglu, Michael A. Kelly, Leonard Nanis, Jamshed R. Patel, Baylor Triplett, Jeffrey Wadsworth, Robert M. White.
*Lecturers:* Ann Marshall, Art Vailionis

* Recalled to active duty.

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Courses in Materials Science and Engineering have the subject code MATSCI. For a complete list of subject codes, see Appendix.

The Department of Materials Science and Engineering (MSE) is concerned with the relation between the structure and properties of materials, factors that control the internal structure of solids, and processes for altering the structure and properties of solids. It brings together in a unified discipline the developments in physical metallurgy, ceramics, and the physics and chemistry of solids. The undergraduate program, described under the "School of Engineering" section of this bulletin, provides training for the materials engineer and also preparatory training for graduate work in materials science. Capable students are encouraged to take at least one year of graduate study to extend their course work to obtain a coterminal MSE degree. Coterminal degree programs are encouraged both for undergraduate majors in Materials Science and Engineering and for undergraduate majors in related disciplines. Graduate programs lead to the degrees of Master of Science, Engineer, and Doctor of Philosophy.

## FACILITIES

The department is based in the Thomas F. Peterson Engineering Laboratory (Building 550), with extensive facilities in the Jack A. McCullough building and the new Gordon and Betty Moore Materials Research Building. These buildings house offices for the chair and most of the faculty, for the administrative and technical staff, and for most graduate students, along with a number of lecture and seminar rooms. Facilities for teaching and research are also available, including equipment for electrical measurements; mechanical testing of bulk and thin film materials; fracture and fatigue of advanced materials; metallography; optical, scanning, transmission electron microscopy, and atomic force microscopy; UHV sputter deposition; vacuum annealing treatments; wet chemistry; and x-ray diffraction. The McCullough/Moore Complex is also the home for the Center for Research on Information Storage Materials (CRISM) with corresponding facilities for magnetic measurements. The Rapid Prototyping Laboratory (RPL), housing material deposition and removal stations, is a joint facility with Mechanical Engineering, and is housed next to the Peterson Labs in Building 530. The department maintains two microcomputer clusters for its students, one with a number of desktop personal computers, and the other with five HP and DEC workstations. Both clusters are linked to the Internet.

Depending on the needs of their programs, students and faculty also conduct research in a number of other departments and independent laboratories. Chief among these are the Center for Integrated Systems (CIS), the Geballe Laboratory for Advanced Materials (GLAM), and the Stanford Synchrotron Radiation Laboratory (SSRL).

The Center for Integrated Systems (CIS) is a laboratory joining government and industrially funded research on microelectronic materials, devices, and systems. It houses a 10,000 square foot, class 100 clean room for Si and GaAs integrated circuit fabrication; a large number of electronic test, materials analysis, and computer facilities; and office space for faculty, staff, and students. In addition, CIS provides startup research funds and maintains a "Fellow-Mentor" program with industry.

For information on GLAM and SSRL, see the "Geballe Laboratory for Advanced Materials" and "Stanford Synchrotron Radiation Laboratory" sections of this bulletin.

## UNDERGRADUATE PROGRAMS

### BACHELOR OF SCIENCE

The undergraduate program provides training in solid state fundamentals and materials engineering. Students desiring to specialize in this field during their undergraduate period may do so by following the curriculum outlined in the "School of Engineering" section of this bulletin as well as the *School of Engineering Undergraduate Handbook*. The University's basic requirements for the bachelor's degree are discussed in the "Undergraduate Degrees" section of this bulletin. Electives are available so that students with broad interests can combine materials science and engineering with work in another science or engineering department.

For information about an MSE minor, see the "School of Engineering" section of this bulletin.

### COTERMINAL B.S./M.S. PROGRAM

Stanford undergraduates who wish to continue their studies for the Master of Science degree in the coterminal program may apply for admission after they have earned 120 units toward graduation (UTG) as shown on the undergraduate unofficial transcript; applicants must submit their application no later than the quarter prior to the expected completion of their undergraduate degree. The application must give evidence that the student possesses the potential for strong academic performance at the graduate level. Each application is evaluated by the department's Admissions Committee. Scores from the Graduate Record Exam (GRE) General Test must be reported before action can be taken on an application. Materials science is a highly integrated and interdisciplinary subject, and so applications from students of any engineering or science undergraduate major are encouraged. Information forms pertaining to the coterminal program may be obtained from the department's student services manager, Room 551F, or from Degree Progress in the Registrar's Office, Old Union. Students entering the coterminal program and receiving both their B.S. and M.S. degree in Materials Science and Engineering at Stanford should also see the "Master of Science for Stanford MSE Students" section below. Coterminal M.S. candidates with undergraduate degrees in other majors should follow the general M.S. degree requirements.

For University coterminal degree program rules and University application forms, see http://registrar.stanford.edu/publications/#Coterm.

## GRADUATE PROGRAMS

Graduate students can specialize in any of the areas of materials science and engineering. Additional special programs are available in collaboration with other departments of the University.

### MASTER OF SCIENCE

The University's basic requirements for the M.S. degree are discussed in the "Graduate Degrees" section of this bulletin. The following are specific departmental requirements.

The Department of Materials Science and Engineering (MSE) requires a minimum of 45 units for a master's degree to be taken in residence at Stanford. Master's Program Proposal forms should be filled out, signed by the student's academic adviser, and submitted to the department's student services manager by the end of the student's first quarter of study. Final changes to the master's program must be submitted no later than one academic quarter prior to degree conferral.

Degree requirements are as follows:

1. A minimum of 33 units of MSE course work, including crosslisted courses, taken for a letter grade with these limitations:
   a) a maximum of 9 units of crosslisted courses may be used in fulfilling this requirement.
   b) one-unit seminars and research units cannot be used to fulfill this requirement.
2. Six courses selected from the core courses 201 through 210 or MATSCI 152 or 251. These core courses count towards the required 33 units of MSE course work, however:
   a) MATSCI 152 does not count for students with materials science undergraduate degrees.
   b) MATSCI 251 may not be used to fulfill this core requirement if the student has a materials science undergraduate degree, although it may be applied towards the required 33 units of MSE course work.
3. Lab courses MATSCI 171, 172, 173 (which count toward the required 33 units of MSE course work).

   *Note:* students who have had equivalent lab courses at other universities, equivalent practical experience, or have a materials related degree or background are expected to file a petition with the department's student services manager to have this requirement waived and to substitute other appropriate technical courses for the lab units.
4. Twelve units of approved course electives that result in a technically coherent program. Of the 12 units of elective courses:
   a) nine of the 12 units must be taken for a letter grade (except for those submitting an M.S. report).
   b) a maximum of 3 units may be seminars.
   c) if writing a master's research report, a minimum of 6 and a maximum of 9 units of MSE research units may be counted. M.S. research units may only be counted if writing an M.S. research report.
   d) a maximum of 3 units may be undergraduate units (offered at Stanford University).
   e) a maximum of 5 units may be used for a foreign language course (not including any remedial English courses or courses in the student's native language if other than English).
   f) the combination of seminar, undergraduate, and language units may not exceed 6 units total.
   g) the combination of research, seminar, undergraduate, and language units may not exceed 12 units total.
5. A minimum grade point average (GPA) of 2.75 for degree course work taken at Stanford.

All proposed degree programs are subject to approval by the department's Academic Degree Committee, which has responsibility for assuring that each proposal is a technically coherent program.

### MASTER'S RESEARCH REPORT

Students wishing to take this option must include 6 to 9 MSE research units on their program proposal and the name of the faculty member who will be supervising the research.

The report must be approved by two faculty members. One faculty member is the student's research adviser. The other faculty member must be approved by the department. Three copies of the report (one copy for each approving faculty member and the department file), in final form and signed by two faculty members, must be submitted to the department's student services manager one week before final examinations of the final quarter of the program. The report is not an official University thesis but rather is intended to demonstrate to department faculty an ability to conduct and report directed research. Refer to the *Materials Science and Engineering Student Handbook* for further clarification concerning this report.

In cases where students decide to pursue research after the initial program submission deadline, they should submit a revised M.S. Program Proposal at least two quarters before the degree is granted. The total combined units of MSE research units, seminars, language courses, and undergraduate courses cannot exceed 12. If a master's research report is not to be submitted, units of MATSCI 200 cannot be applied to the department's requirement of 45 units for the master's degree.

### MASTER'S DEGREE FOR STANFORD UNIVERSITY MSE BACHELOR'S DEGREE STUDENTS

The University's basic requirements for the M.S. degree are discussed in the "Graduate Degrees" section of this bulletin. The following are specific departmental requirements.

The Department of Materials Science and Engineering (MSE) requires a minimum of 45 units for a master's degree. Students who have received or are currently working towards a B.S. degree in Materials Science and Engineering from Stanford and are pursuing an M.S. in Materials Science and Engineering should follow the requirements below in lieu of those stated in the "Master of Science" section above. Master's Program Proposal forms should be completed, signed by the student's academic adviser, and submitted to the department's student services manager by the end of the student's first quarter of study. Final changes to the master's program must be submitted no later than one academic quarter prior to degree conferral.

Degree requirements for students entering after September 1, 2001 are:

1. Three of the remaining core classes, MATSCI 201-210.
2. 12 units of non-crosslisted MSE 300-level courses (not including MATSCI 300 Ph.D. research).
3. 24 units of approved elective courses that constitute a technically coherent program. Of the 24 units of elective courses:
   a) 21 of the 24 units must be taken for a letter grade (except for those submitting an M.S. report).
   b) a maximum of 3 units may be seminars.
   c) if writing a Master's Research Report, a minimum of 6 and a maximum of 9 units of M.S. research units (MATSCI 200) may be used.*
   d) a maximum of 6 units may be undergraduate units.
   e) a maximum of 5 units may be used for a foreign language course (not including any remedial English courses or courses in the student's native language if it is not English).
   f) the combination of seminar, undergraduate, and language units may not exceed 9 units total.
   g) the combination of research, seminar, undergraduate, and language units may not exceed 15 units total.
3. A minimum grade point average (GPA) of 2.75 for degree course work at Stanford.

* See the Master's Research Report above for information on Research Report requirements.

### HONORS COOPERATIVE PROGRAM

Some of the department's graduate students participate in the Honors Cooperative Program (HCP), which makes it possible for academically qualified engineers and scientists in industry to be part-time graduate students in Materials Science while continuing professional employment. Prospective HCP students follow the same admissions process and must meet the same admissions requirements as full-time graduate students. For information regarding the Honors Cooperative Program, see the "School of Engineering" section of this bulletin.

### PETITION PROCESS FOR TRANSFER FROM M.S. TO PH.D. DEGREE PROGRAM

When a student is admitted to the graduate program, he or she is admitted specifically into either the M.S. or the Ph.D. program. Admission to the Ph.D. program is required for the student to be eligible to work towards the Ph.D. degree. A student in the M.S. program can petition to be admitted to the Ph.D. program by filing an M.S. to Ph.D. Transfer Petition.

This petition must be accompanied by a one-page statement of purpose stating the reasons why the student wishes to transfer to the Ph.D. program, and two letters of recommendation from members of the Stanford faculty, including one from the student's prospective adviser and at least one from an MSE faculty member belonging to the Academic Council.

The M.S. to Ph.D. Transfer Petition is due to the student services manager by the end of the second week of Spring Quarter during the student's first year in the M.S. program. Only students enrolled in the 200 series core course sequence are eligible to petition, and a grade point average (GPA) of 3.25 or better in the core courses is required.

Transferring to the Ph.D. program is a competitive process and only fully qualified M.S. students are admitted. The Admissions Committee and the department chair consider the student's original application to the graduate program as well as the material provided with the transfer petition.

## ENGINEER

The University's basic requirements for the degree of Engineer are outlined in the "Graduate Degrees" section of this bulletin.

A student wishing to enter the Engineer program must have completed the substantial equivalent requirements of the M.S. in Materials Science and Engineering, and must file a petition requesting admission to the program, stating the type of research to be done and the proposed supervising professor. Once approved, the Application for Candidacy must be submitted to the department's student services manager by the end of the second quarter in the Engineer program. Final changes in the Application for Candidacy form must be submitted no later than one academic quarter prior to degree conferral.

The 90-unit program must include 9 units of graduate non-crosslisted courses in materials science (exclusive of research units, seminars, colloquia, MATSCI 400, Participation in Teaching, and so on) beyond the requirements for the M.S. degree, and additional research or other units to meet the 90-unit University minimum requirement. A grade point average (GPA) of 3.0 must be maintained for all degree course work taken at Stanford.

Completion of an acceptable thesis is required. The Engineer thesis must be approved by two Academic Council faculty members, one of whom must be a member of the department, and submitted in triplicate.

## DOCTOR OF PHILOSOPHY

The University's basic requirements for the Ph.D. degree are outlined in the "Graduate Degrees" section of this bulletin.

Degree requirements are as follows:

1. Submit a Ph.D. program consisting of at least 135 units,† which contains a minimum of 57 technical course units. Of these 57 units:
   a) at least 54 of the 57 units must be for a letter grade
   b) 33 units must be taken as non-crosslisted MSE courses for a letter grade
   c) all students must take six core courses*
      1) 203, 204, and 207 are required of all students in their first year
      2) all students must take three additional core courses in their first year as follows:
         a) either 205 or 206
         b) two of 208, 209, or 210
   d) a minimum of 12 units of 300-level courses from the MSE faculty (not including MATSCI 300, Ph.D. Research)
   e) a minimum of 12 units of courses taken from one of the following lists of advanced specialty courses (see below). Some and/or all of these courses can be the same as the courses used to meet the requirement of 12 units of 300-level courses; however, the units may not be counted twice toward the 57 technical units or the 135 total degree units.

   f) the remaining units beyond the 57 units of technical course work may consist of Ph.D. research, seminars, teaching experience, and so on.
2. First-year Ph.D. students are required to take the MSE Colloquium, MATSCI 230, each quarter of their first year.
3. Pass a departmental oral qualifying examination by the end of January of their second year. A grade point average (GPA) of 3.25 from the six core classes taken (201-210) is required for admission to the Ph.D. qualifying exam. Students whose GPA is between 3.00 and 3.25 may petition for admission to the exam. Students who have passed the departmental oral examination are required to complete the Application for Candidacy for the Ph.D. Degree by the end of the quarter in which they pass the exam. Final changes in the Application for Candidacy form must be submitted no later than one academic quarter prior to degree conferral.
4. Serve as a teaching assistant one quarter during the Ph.D. program. MATSCI 400, Participation in Materials Science Teaching, may be taken to grant formal credit for this work.
5. Maintain a GPA of 3.0 in all degree courses taken at Stanford.
6. Present the result of the dissertation at a department seminar immediately preceding the University oral examination.

* Students may, if they have sufficient background, petition out of some of the required core courses. To successfully petition, students must have prior permission from their academic adviser, and also permission from the instructor of the particular core course. That instructor provides an oral or written examination that the petitioning student must pass.

† At least 90 units must be taken in residence at Stanford. Students entering with an M.S. degree in Materials Science from another university may request to transfer up to 45 units of equivalent work toward the total of 135 required units.

### ADVANCED SPECIALTY COURSES

1. Biomaterials: APPPHYS 192; BIOPHYS 228; CHEMENG 260, 310A, 350, 355, 444A, 452; ME 283, 284, 381, 385A,B, 386, 457
2. Electronic Materials Processing: EE 212, 216, 217, 311, 316, 410; MATSCI 312, 313, 330
3. Materials Characterization: APPPHYS 216, 218; CHEMENG 345; EE 329; MATSCI 320, 321, 322, 323, 324, 325
4. Mechanical Behavior of Solids: AA 252, 256; MATSCI 251, 270, 352, 353, 354A, 355, 356, 358, 359; ME 335A,B,C, 338, 340B
5. Physics of Solids and Computation: APPPHYS 218, 272, 273, 372, 373; CHEMENG 444A; EE 222, 223, 228, 327, 328, 329; MATSCI 330, 343, 347, 349, 359; ME 344A,B, 444B
6. Soft Materials: CHEMENG 260, 310A, 460, 462; MATSCI 343

### PH.D. MINOR

The University's basic requirements for the Ph.D. minor are outlined in the "Graduate Degrees" section of this bulletin. A minor requires 20 units of graduate work of quality and depth to be approved by the Advanced Degree Committee of the department. Individual programs must be submitted to the Student Services Manager at least one quarter prior to degree conferral and approved as are other academic plans.

## COURSES

### PRIMARILY FOR UNDERGRADUATES

**MATSCI 31. Introduction to Solid State Chemistry with Application to Materials Technology**—(Enroll in ENGR 31.)
*4 units, Aut (McIntyre)*

**MATSCI 50. Introductory Science of Materials**—(Enroll in ENGR 50.)
*4 units, Win (Melosh), Spr (Sinclair)*

**MATSCI 70N. Building the Future: Invention and Innovation with Engineering Materials**—Stanford Introductory Seminar. Preference to freshmen. The technological importance of materials in human civilization is captured in historical names such as the Stone, Bronze, and Iron Ages. The present Information Age could rightly be called the Silicon Age. The pivotal roles of materials in the development of new technologies. Quantitative problem sets, field trips, and formal presentations of small-group projects. GER:2b,WR2
*5 units, Spr (Bravman)*

**MATSCI 100. Undergraduate Independent Study**—Independent study in materials science under supervision of a faculty member.
*1-3 units, Aut, Win, Spr, Sum (Staff)*

**MATSCI 150. Undergraduate Research**—Participation in a research project.
*3-6 units, Aut, Win, Spr, Sum (Staff)*

**MATSCI 151. Microstructure and Mechanical Properties**—(For undergraduates; see 251.)
*4 units, Aut (Dauskardt)*

**MATSCI 152. Electronic Materials Engineering**—Materials science and engineering for information technology applications. Kinetic molecular theory and thermally activated processes; band structure and electrical conductivity of metals and semiconductors; intrinsic and extrinsic semiconductors; diffusion; elementary p-n junction theory; operating principles of metal-oxide-semiconductor field effect transistors; introduction to crystal growth; oxidation kinetics; ion implantation; thermodynamics and kinetics of chemical vapor deposition; survey of physical vapor deposition methods, etching, and photolithography. GER:2b
*3 units, Spr (McIntyre)*

**MATSCI 159Q. Research in Japanese Companies**—Stanford Introductory Seminar (Same as ENGR 159Q.) Preference to sophomores. The structure of a Japanese company from the point of view of Japanese society. Visiting researchers from Japanese companies give presentations on their research enterprise, with question and answer periods. Exploration of the Japanese research ethic. The home campus equivalent of a Kyoto SCTI course. GER:3b
*3 units, Spr (Sinclair)*

**MATSCI 161. Materials Science Lab I**—(Same as 171.) For undergraduates. The development of standard lab procedures for materials scientists with an emphasis on microscopy, metallography, and technical writing. Techniques: optical, scanning-electron, atomic-force microscopy, and metallographic specimen preparation. The relationships between microscopic observation, material properties, and processing. Prerequisite: ENGR 50 or equivalent. GER:2b
*4 units, Aut (Staff)*

**MATSCI 162. Materials Science Lab II**—(Same as 172.) For undergraduates. Introduction to x-ray diffraction for microstructural analysis of materials, emphasizing powder and single-crystal techniques. Diffraction from thin films, thin-film multilayers, amorphorous materials, strain measurements, orientation measurements, and electron diffraction. Prerequisite: 193/203. GER:2b,WIM
*4 units, Win (Vailionis)*

**MATSCI 163. Materials Science Labs III**—(Same as 173.) For undergraduates. Lab on experimental techniques for the study of the mechanical properties of materials, including fracture toughness testing of metallic materials, ductile-to-brittle transition curves, fracture of ceramics using indentation techniques, and effects of grain size on yielding and strain hardening. Prerequisites: 198/208, 151/251, or equivalent. GER:2b
*4 units, Spr (Staff)*

**MATSCI 170. Materials Selection In Design**—(For undergraduates; see 270.)
*4 units (Prinz) not given 2004-05*

**MATSCI 171. Materials Science Lab I**—(For graduate students; see 161.)
*3 units, Aut (Staff)*

**MATSCI 172. Materials Science Lab II**—(For graduate students; see 162.)
*3 units, Win (Vailionis)*

**MATSCI 173. Materials Science Labs III**—(For graduate students; see 163.)
*3 units, Spr (Staff)*

**MATSCI 190. Organic Materials**—(For undergraduates; see 210.)
*4 units, Aut (McGehee)*

**MATSCI 191. Mathematical and Computational Methods in Materials Science**—(For undergraduates; see 201.)
*4 units, Aut (Barnett)*

**MATSCI 192. Solid State Thermodynamics**—(For undergraduates; see 202.)
*4 units, Aut (Barnett)*

**MATSCI 193. Atomic Arrangements in Solids**—(For undergraduates; see 203.)
*4 units, Aut (Sinclair)*

**MATSCI 194. Phase Equilibria**—(For undergraduates; see 204.)
*4 units, Win (McIntyre)*

**MATSCI 195. Waves and Diffraction in Solids**—(For undergraduates; see 205.)
*4 units, Win (Clemens)*

**MATSCI 196. Imperfections in Crystalline Solids**—(For undergraduates; see 206.)
*4 units (Staff) not given 2004-05*

**MATSCI 197. Rate Processes in Materials**—(For undergraduates; see 207.)
*4 units, Spr (Clemens)*

**MATSCI 198. Mechanical Properties of Materials**—(For undergraduates; see 208.)
*4 units, Spr (Dauskardt)*

**MATSCI 199. Electronic and Optical Properties of Solids**—(For undergraduates; see 209.)
*4 units, Spr (Brongersma)*

## PRIMARILY FOR GRADUATE STUDENTS

**MATSCI 200. Master's Research**—Participation in a research project.
*1-9 units Aut, Win, Spr, Sum (Staff)*

**MATSCI 201. Mathematical and Computational Methods in Materials Science**—(Same as 191.) This year's topics: mathematical methods associated with crystal physics including the reciprocal lattice, matrices, eigenvalues, waves, small vibrations of crystals, normal modes, and variational calculus. In subsequent years: diffusion, waves in a continuum, and tensor properties of crystals. Prerequisite: familiarity with simple ordinary differential equations. GER:2b
*3 units, Aut (Barnett)*

**MATSCI 202. Solid State Thermodynamics**—(Same as 192.) The principles of thermodynamics and relationships between thermodynamic variables. Equilibrium in thermodynamic systems. Elementary statistical thermodynamics. Thermodynamics of multicomponent systems. Prerequisite: physical chemistry or introductory thermodynamics. GER:2b
*3 units, Aut (Barnett)*

**MATSCI 203. Atomic Arrangements in Solids**—(Same as 193.) Atomic arrangements in perfect and imperfect crystalline solids, especially important metals, ceramics, and semiconductors. Elements of formal crystallography, including development of point groups and space groups. GER:2b
*3 units, Aut (Sinclair)*

**MATSCI 204. Phase Equilibria**—(Same as 194.) The principles of heterogeneous equilibria and their application to phase diagrams. Thermodynamics of solutions; chemical reactions; non-stoichiometry in compounds; first order phase transitions and metastability; higher order transitions; statistical models of alloy thermodynamics; binary and ternary phase diagram construction; thermodynamics of surfaces. Prerequisite: 192/202; or consent of instructor. GER:2b
*3 units, Win (McIntyre)*

**MATSCI 205. Waves and Diffraction in Solids**—(Same as 195.) The elementary principals of x-ray, vibrational, and electron waves in solids. Basic wave behavior including Fourier analysis, interference, diffraction, and polarization. Examples of wave systems, including electromagnetic waves from Maxwell's equations. Diffracted intensity in reciprocal space and experimental techniques such as electron and x-ray diffraction. Lattice vibrations in solids, including vibrational modes, dispersion relationship, density of states, and thermal properties. Free electron model. Basic quantum mechanics and statistical mechanics including Fermi-Dirac and Bose-Einstein statistics. Prerequisite: 193/203 or consent of instructor. GER:2b
*3 units, Win (Clemens)*

**MATSCI 206. Imperfections in Crystalline Solids**—(Same as 196.) The relation of lattice defects to the physical and mechanical properties of crystalline solids. Introduction to point imperfections and their relationship to transport properties in metallic, covalent, and ionic crystals. Geometric, crystallographic, elastic, and energetic properties of dislocations. Relations between dislocations and the mechanical properties of crystals. Introduction to the structure and properties of interfaces in solids. Prerequisite: 193/203. GER:2b
*3 units (Staff) not given 2004-05*

**MATSCI 207. Rate Processes in Materials**—(Same as 197.) Diffusion and phase transformations in solids. Diffusion topics: Fick's laws, atomic theory of diffusion, and diffusion in alloys. Phase transformation topics: nucleation, growth, diffusional transformations, spinodal decomposition, and interface phenomena. Material builds on the mathematical, thermodynamic, and statistical mechanical foundations in the prerequisites. Prerequisites: 194/204. GER:2b
*3 units, Spr (Clemens)*

**MATSCI 208. Mechanical Properties of Materials**—(Same as 198.) Introduction to the mechanical behavior of solids, emphasizing the relationships between microstructure and mechanical properties. Elastic, anelastic, and plastic properties of materials. The relations between stress, strain, strain rate, and temperature for plastically deformable solids. Application of dislocation theory to strengthening mechanisms in crystalline solids. The phenomena of creep, fracture, and fatigue and their controlling mechanisms. Prerequisites: 193/203, 196/206. GER:2b
*3 units, Spr (Dauskardt)*

**MATSCI 209. Electronic and Optical Properties of Solids**—(Same as 199.) The concepts of electronic energy bands and transports applied to metals, semiconductors, and insulators. The behavior of electronic and optical devices including p-n junctions, MOS-capacitors, MOSFETs, optical waveguides, quantum-well lasers, light amplifiers, and metallo-dielectric light guides. Emphasis is on relationships between structure and physical properties. Elementary quantum and statistical mechanics concepts are used. Prerequisite: 195/205 or equivalent. GER:2b
*3 units, Spr (Brongersma)*

**MATSCI 210. Organic Materials**—(Same as 190.) Bonding and intermolecular interactions in organic materials. Techniques for determining the chemical structure and molecular packing of organic materials. Relationship between the structure and physical properties of polymers, liquid crystals, and other macromolecules. Introduction to synthesizing organic macromolecules. Current technological applications for organic materials such as flexible flat panel displays. GER:2b
*3 units, Aut (McGehee)*

**MATSCI 230. Materials Science Colloquium**—May be repeated for credit. (AU)
*1 unit, Aut, Win, Spr (Staff)*

**MATSCI 251. Microstructure and Mechanical Properties**—(Same as 151.) Primarily for students without a materials background. Mechanical properties and their dependence on microstructure in a range of engineering materials. Elementary deformation and fracture concepts, strengthening and toughening strategies in metals and ceramics. Topics: dislocation theory, mechanisms of hardening and toughening, fracture, fatigue, and high-temperature creep. Prerequisite: ENGR 50 or equivalent. GER:2b
*3 units, Aut (Dauskardt)*

**MATSCI 270. Materials Selection In Design**—(Same as 170.) Methods to select materials for engineering applications, emphasizing structural and thermal properties. Fundamentals of the interrelation between materials parameters. Strategies for optimal selection subject to performance, processing, and manufacturing constraints. Materials selection with and without shape considerations. Use of materials databases. Design case studies. Material synthesis methodologies. Prerequisite: ENGR 14 and 50 or ME 111. GER:2b
*3 units (Prinz) not given 2004-05*

**MATSCI 273. Magnetism and Long Range Order in Solids**—(Enroll in APPPHYS 270.)
*3 units (Fisher) not given 2004-05*

**MATSCI 299. Practical Training**—Educational opportunities in high-technology research and development labs in industry. Qualified graduate students engage in internship work and integrate that work into their academic program. Following the internship, students complete a research report outlining their work activity, problems investigated, key results, and any follow-on projects they expect to perform. Student is responsible for arranging own employment. See department student services manager before enrolling.
*3 units, Aut, Win, Spr, Sum (Staff)*

**MATSCI 300. Ph.D. Research**—Participation in a research project.
*1-15 units, Aut, Win, Spr, Sum (Staff)*

**MATSCI 310. Integrated Circuit Fabrication Processes**—(Enroll in EE 212.)
*3 units, Aut (Plummer)*

**MATSCI 312. New Methods in Thin Film Synthesis**—Materials base for engineering new classes of coatings and devices. Techniques to grow thin films at atomic scale and to fabricate multilayers/superlattices at nanoscale. Fundamentals of vacuum growth techniques including evaporation, molecular beam epitaxy (MBE), sputtering, ion beam assisted deposition, laser ablation, chemical vapor deposition (CVD), and electroplating. Future direction of material synthesis such as nonocluster deposition and nanoparticles self-assembly. Relationships between deposition parameters and film properties. Applications of thin film synthesis in microelectronics, nanotechnology, and biology. SITN/SCPD televised.
*3 units (Wang) not given 2004-05*

**MATSCI 313. Synthesis and Processing of Bulk and Thin Film Ceramics**—Unit process operations used to fabricate polycrystalline ceramic components and thin films. Topics: grain growth, solid state and liquid phase sintering, drying, forming processes, particle packing effects, powder synthesis through solid state reaction and wet chemical methods, thin film deposition via sol gel and vapor phase synthesis routes. Prerequisites: 204 and 207, or equivalents.
*3 units (McIntyre) alternate years, given 2005-06*

**MATSCI 315. Polymer Surfaces and Interfaces**—(Enroll in CHEMENG 460.)
*3 units (Frank) alternate years, not given 2005-06*

**MATSCI 316. Nanoscale Science, Engineering, and Technology**—Overview of nanotechnology with an emphasis on self-assembly and molecular electronics. Topics: intermolecular interactions; self-assembly of amphiphilic molecules, block copolymers, organic-inorganic mesostructures, colloidal crystals, proteins, DNA and abalone shells; biologically inspired growth of materials; scanning probe microscopy and lithography; carbon nanotubes; organic semiconductors; nanoelectronics; molecular electronics. Other nanotechnology topics may be explored through a group project. Prerequisite: knowledge of how conventional silicon transistors are fabricated and how they function. SITN/SCPD televised.
*3 units, Win (McGehee)*

**MATSCI 317. Advanced Integrated Circuit Fabrication Processes**—(Enroll in EE 311.)
*3 units, Spr (Saraswat)*

**MATSCI 318. Integrated Circuit Fabrication Laboratory**—(Enroll in EE 410.)
*3-4 units, Win (Saraswat)*

**MATSCI 319. Electron and Ion Beams for Semiconductor Processing**—(Enroll in EE 217.)
*3 units (Pease) alternate years, given 2005-06*

**MATSCI 320. Nanocharacterization of Materials**—Current methods of directly examining the microstructure of materials. Topics: optical microscopy, scanning electron and focused ion beam microscopy, field ion microscopy, transmission electron microscopy, scanning probe microscopy, and microanalytical surface science methods. Emphasis is on the electron-optical techniques. Recommended: 193/203.
*3 units (Sinclair) alternate years, given 2005-06*

**MATSCI 321. Transmission Electron Microscopy**—Image formation and interpretation. The contrast phenomena associated with perfect and imperfect crystals from a physical point of view and from a formal treatment of electron diffraction theory. The importance of electron diffraction to systematic analysis and recent imaging developments. Prerequisite: 193/203, 195/205, or equivalent.
*3 units, Win (Sinclair) alternate years, not given 2005-06*

**MATSCI 322. Transmission Electron Microscopy Laboratory**—Experimental application of electron microscopy to typical materials science studies. Topics include microscope operation and alignment, diffraction modes and analysis, bright-field/dark-field analysis of defects, high resolution imaging, and analytical techniques for compositional analysis (EDAX). Prerequisites: 321, consent of instructor.
*3 units, Spr (Marshall)*

**MATSCI 323. Thin Film and Interface Microanalysis**—The science and technology of a variety of microanalytical techniques, including Auger electron spectroscopy (AES), Rutherford backscattering spectroscopy (RBS), secondary ion mass spectroscopy (SIMS), ion scattering spectroscopy (ISS), and x-ray photoelectron spectroscopy (XPS or ESCA). Generic processes such as sputtering and high-vacuum generation. Prerequisite: some prior exposure to atomic and electronic structure of solids. SITN/SCPD televised.
*3 units, Aut (Brongersma)*

**MATSCI 324. Topics in Thin Film Microcharacterization**—Case study characterizing materials, defining problems in characterizing surfaces or thin films, carrying out analyses of relevant samples, and reporting the results. Students propose problems, and operate modern electron, ion, and x-ray probe instruments to study samples. Methodology for approaching characterization problems; experience in interpreting and presenting experimental results. Emphasis is on application of advanced measurement methods to practical problems, and capabilities and limitations of modern techniques. Topics: choosing the appropriate techniques, analytical pitfalls, quantitative analysis, effects of noise and other uncertainties on analytical precision. Enrollment limited. Prerequisite: 323 or consent of instructor.
*3 units, Win (Kelly) alternate years, not given 2005-06*

**MATSCI 325. X-Ray Diffraction**—Diffraction theory and its relationship to structural determination in solids. Focus is on applications of x-rays; concepts can be applied to neutron and electron diffraction. Topics: Fourier analysis, kinematic theory, Patterson functions, diffraction from layered and amorphous materials, single crystal diffraction, dynamic theory, defect determination, surface diffraction, techniques for data analysis, and determination of particle size and strain. Prerequisites: 193/203, 195/205.
*3 units, Aut (Clemens) alternate years, not given 2005-06*

**MATSCI 327. X-Ray and Neutron Scattering in the 21st Century**—(Enroll in APPPHYS 218.)
*3 units, Spr (Greven)*

**MATSCI 330. Metal Oxide-Based Electronics**—Electronic and ionic conduction, and dielectric, piezoelectric, and opto-electronic properties

of advanced ceramic materials. Behavior of bulk polycrystalline ceramics and thin films. Relationships among processing history, microstructure, point defect chemistry, and the functional properties of ceramic. Application areas: high permittivity on-chip capacitor dielectrics, piezoelectric sensors/actuators, fast ion conductors, electrical and thermal transducers, and electro-optic devices. Prerequisite: 209 or equivalent.
*3 units (McIntyre) alternate years, given 2005-06*

**MATSCI 331. Solid State Physics I**—(Enroll in APPPHYS 272.)
*3 units, Win (Manoharan)*

**MATSCI 332. Solid State Physics II**—(Enroll in APPPHYS 273.)
*3 units, Spr (Manoharan)*

**MATSCI 334. Basic Physics for Solid State Electronics**—(Enroll in EE 228.)
*3 units, Aut (Peumans)*

**MATSCI 335. Properties of Semiconductor Materials**—(Enroll in EE 327.)
*3 units, Spr (J. Harris) alternate years, not given 2005-06*

**MATSCI 336. Physics of Advanced Semiconductor Devices**—(Enroll in EE 328.)
*3 units (J. Harris) alternate years, given 2005-06*

**MATSCI 341. Principles and Models of Semiconductor Devices**—(Enroll in EE 216.)
*3 units, Aut, (J. Harris), Win (Saraswat, Pease)*

**MATSCI 342. The Electronic Structure of Surfaces and Interfaces**—(Enroll in EE 329.)
*3 units, Aut (Pianetta) alternate years, not given 2005-06*

**MATSCI 343. Organic Semiconductors for Electronics and Photonics**—The science of organic semiconductors and their use in electronic and photonic devices. Topics: methods for fabricating thin films and devices; relationship between chemical structure and molecular packing on properties such as band gap, charge carrier mobility and luminescence efficiency; doping; field-effect transistors; light-emitting diodes; lasers; biosensors; photodetectors and photovoltaic cells. SITN/SCPD televised.
*3 units, Spr (McGehee)*

**MATSCI 344. Micromachined Sensors and Actuators**—(Enroll in EE 312.)
*3 units (Kovacs) not given 2004-05*

**MATSCI 345. Advanced VLSI Devices**—(Enroll in EE 316.)
*3 units, Win (Wong)*

**MATSCI 346. Nanophotonics**—(Same as EE 336.) Recent developments in micro- and nanophotonic materials and devices. Basic concepts of photonic crystals. Integrated photonic circuits. Photonic crystal fibers. Superprism effects. Optical properties of metallic nanostructures. Subwavelength phenomena and plasmonic excitations. Meta-materials.
*3 units, Win (Fan, Brongersma)*

**MATSCI 347. Introduction to Magnetism and Magnetic Nanostructures**—Atomic origins of magnetic moments, magnetic exchange and ferromagnetism, types of magnetic order, magnetic anisotropy, domains, domain walls, hysteresis loops, hard and soft magnetic materials, demagnetization factors, and applications of magnetic materials, especially magnetic nanostructures and nanotechnology. Basic tools include finite-element and micromagnetic modeling. Design topics include electromagnet and permanent magnet, electronic article surveillance, magnetic inductors, bio-magnetic sensors, and magnetic drug delivery. Focus is on design projects, team work, and computer-aided design. Prerequisites: PHYSICS 53 and 57, or equivalents.
*3 units (Wang) not given 2004-05*

**MATSCI 349. Introduction to Information Storage Systems**—(Enroll in EE 335.)
*3 units, Win (Richter)*

**MATSCI 352. Stress Analysis in Thin Films and Layered Composite Media**—Introduction to methods of stress analysis of layered dissimilar media, including thin films deposited on substrates, composite laminates, and stratified anisotropic elastic materials based on techniques pioneered by Stroh. Stress states generated by thermal and elastic mismatch and local stress concentrations at interfacial cracks or corners, with applications to integrated circuit devices, aircraft materials, and geophysical media. Prerequisites: introductory course on the strength of materials or the theory of elasticity, some familiarity with matrix algebra.
*3 units (Barnett) alternate years, given 2005-06*

**MATSCI 354A. Theory and Applications of Elasticity**—(Enroll in ME 340A.)
*3 units (Barnett) not given 2004-05*

**MATSCI 356. Fatigue Design and Analysis**—(Enroll in ME 345.)
*3 units, Win (Nelson)*

**MATSCI 357. Physical Solid Mechanics**—(Enroll in ME 329.)
*3 units, Aut (Cho)*

**MATSCI 358. Fracture and Fatigue of Engineering Materials**—Linear-elastic and elastic-plastic fracture mechanics from a materials science perspective, emphasizing microstructure and the micromechanisms of fracture. Plane strain fracture toughness and resistance curve behavior. Mechanisms of failure associated with cleavage and ductile fracture in metallic materials and brittle fracture of ceramics and their composites. Fracture mechanics approaches to toughening and subcritical crack-growth processes, with examples and applications in advanced materials including cyclic fatigue and high-temperature creep of metals and ceramics. Prerequisite: 151/251, 198/208, or equivalent.
*3 units, Win (Dauskardt)*

**MATSCI 360. Techniques of Failure Analysis**—(Enroll in AA 252.)
*2 units, Spr (Ross)*

**MATSCI 361. Mechanics of Composites**—(Enroll in AA 256.)
*3 units, Win (Springer)*

**MATSCI 371A. Computational Nanotechnology**—(Enroll in ME 344A.)
*3 units, Win (Cho)*

**MATSCI 371B. Nanomaterials Modeling**—(Enroll in ME 344B.)
*3 units, Spr (Cho)*

**MATSCI 372. Quantum Simulations of Molecules and Materials**—(Enroll in CHEMENG 444A.)
*3 units (Staff) not given 2004-05*

**MATSCI 380. Molecular Biomaterials**—For students with engineering backgrounds interested in the interface between biology and materials science The characteristics of natural and man-made biomaterials from a molecular perspective. Why molecules with particular structures and properties are used for drug delivery, cell scaffolding, and surface passivation. Goal is to exploit these characteristics to create new materials and devices. Engineering strategies to interface biological species with inorganic, man-made devices.
*3 units, Aut (Melosh)*

**MATSCI 400. Participation in Materials Science Teaching**—May be repeated for credit.
*1-3 units, Aut, Win, Spr (Staff)*

**MATSCI 405. Seminar in Applications of Transmission Electron Microscopy**—Can be repeated for credit. (AU)
*1 unit, Aut, Win, Spr (Sinclair)*

**MATSCI 459. Frontiers in Interdisciplinary Biosciences**—(Cross-listed in departments in the schools of H&S, Engineering, and Medicine; student register through their affiliated departments; otherwise register for CHEMENG 459) See CHEMENG 459 or http://biox.stanford.edu/courses/459_announce.html.
*1 unit, Aut, Win, Spr (Robertson)*

# MECHANICAL ENGINEERING

*Emeriti: (Professors)* James L. Adams, Holt Ashley,* Peter Bradshaw, Thomas J. Connolly, Daniel B. DeBra,* Robert H. Eustis, Joel H. Ferziger, George Herrmann, Thomas J. R. Hughes, James P. Johnston, Thomas R. Kane, William M. Kays, Joseph B. Keller, Robert McKim, Robert J. Moffat, J. David Powell,* Rudolph Sher, Charles R. Steele, Milton D. Van Dyke, Douglass J. Wilde; *(Professors, Research)* Elliot Levinthal, Sidney Self, Felix Zajac

*Mechanical Engineering Executive Committee:* Mark R. Cutkosky (Faculty Affairs), John K. Eaton (Vice Chairman), Reginald E. Mitchell (Student Services and Undergraduate Curriculum), Friedrich B. Prinz (Chairman, Mechanical Engineering), Sheri D. Sheppard (Graduate Admissions and Curriculum)

*Group Chairs*: Thomas P. Andriacchi (Biomechanical Engineering), Reginald E. Mitchell (Thermosciences), Peter M. Pinsky (Mechanics and Computation); (Design and Flow Physics and Computation groups operate without chairs)

*Laboratory Directors:* David W. Beach (Product Realization Laboratory), J. Edward Carryer (Smart Product Design Laboratory), Mark R. Cutkosky (Manufacturing Sciences Lab), Christopher Jacobs (Veterans Affairs Rehabilitation R&D Center), John K. Eaton (Heat Transfer and Turbulence Mechanics), Kosuke Ishii (Manufacturing Modeling Laboratory), Larry J. Leifer (Center for Design Research), Reginald E. Mitchell (High Temperature Gasdynamics), Parviz Moin (Center for Turbulence Research), Friedrich B. Prinz (Rapid Prototyping Laboratory)

*Professors:* Thomas P. Andriacchi, David M. Barnett, Craig T. Bowman, Brian J. Cantwell, Dennis R. Carter, Mark R. Cutkosky, John K. Eaton, Charbel Farhat, Ronald K. Hanson, Kosuke Ishii, David M. Kelley, Charles H. Kruger, Larry J. Leifer, Sanjiva Lele, Parviz Moin, M. Godfrey Mungal, Drew V. Nelson, Peter M. Pinsky, Friedrich B. Prinz, Bernard Roth, Eric Shaqfeh

*Associate Professors:* Mark A. Cappelli, Scott Delp, Christopher Edwards, Kenneth E. Goodson, Thomas W. Kenny, Reginald E. Mitchell, Sheri D. Sheppard

*Assistant Professors:* Wei Cai, Kyeongjae Cho, Eric Darve, J. Christian Gerdes, Andrian Lew, Gunter Niemeyer, Heinz Pitsch, Beth Pruitt, Juan G. Santiago, Charles Taylor

*Acting Assistant Professor:* George Kembel

*Professors (Research):* Richard M. Christensen, Paul Durbin, Kenneth Waldron

*Associate Professor (Research):* Christopher Jacobs

*Professor (Teaching):* David W. Beach

*Courtesy Professors:* Fu-Kuo Chang, George S. Springer, Robert T. Street, Paul Yock

*Senior Lecturer:* J. Craig Milroy

*Lecturers:* Nalu B. Kaahaaina, Matthew R. Ohline

*Consulting Professors:* Gary S. Beaupre, David M. Golden, Barry M. Katz, Victor D. Scheinman, Edith Wilson

*Consulting Associate Professor:* J. Edward Carryer

*Consulting Assistant Professors:* Michael Barry, Mark Bolas, Brendan J. Boyle, William Burnett, Vadim Khayms, Sara Little Turnbull

*Visiting Professor:* Huajian Gao

* Recalled to active duty.

*Student Services:* Building 530, Room 125
*Mail Code:* 94305-3030
*Student Services Phone:* (650) 725-7695
*Web Site:* http://me.stanford.edu

Courses given in Mechanical Engineering have the subject code ME. For a complete list of subject codes, see Appendix.

The programs in the Department of Mechanical Engineering (ME) are designed to provide background for a wide variety of careers. The discipline is very broad, but is generally understood to emphasize an appropriate mix of applied mechanics, biomechanical engineering, computer simulations, design, and energy science and technology. Graduates at all degree levels have traditionally entered into energy industries, product manufacturing industries, transportation, government laboratories and agencies dealing with these problems, and a variety of academic positions.

Since mechanical engineering is a broad discipline, the undergraduate program can be a springboard for graduate study in business, law, medicine, political science, and other professions where a good understanding of technology is often important. Both undergraduate and graduate programs provide excellent technical background for work in biomechanical engineering, environmental pollution control, ocean engineering, transportation, and on other multidisciplinary problems that concern society. Throughout the various programs, considerable emphasis is placed on developing systematic procedures for analysis, effective communication of one's work and ideas, practical and aesthetic aspects in design, and responsible use of technology. This can provide a student with an approach and a philosophy of great utility, irrespective of an ultimate career.

The department has five groups: Biomechanical Engineering, Design, Flow Physics and Computation, Mechanics and Computation, and Thermosciences. Each maintains its own labs, shops, and offices.

The Biomechanical Engineering (BME) Group has teaching and research activities which focus primarily on musculoskeletal biomechanics, neuromuscular biomechanics, cardiovascular biomechanics, and rehabilitation engineering. Research in other areas including hearing, ocean, plant, and vision biomechanics exist in collaboration with associated faculty in biology, engineering, and medicine. The Biomechanical Engineering Group has particularly strong research interactions with the Mechanics and Computation and the Design groups, and the departments of Functional Restoration, Neurology, Radiology, and Surgery in the School of Medicine.

The Design Group emphasizes cognitive skill development for creative design. It is concerned with automatic control, computer-aided design, creativity, design aesthetics, design for manufacturability, design research, experimental stress analysis, fatigue and fracture mechanics, finite element analysis, human factors, kinematics, manufacturing systems, microcomputers in design, micro-electromechanics systems (MEMS, robotics, and vehicle dynamics. The Design Group offers undergraduate and graduate programs in Product Design (jointly with the Department of Art and Art History).

The Flow Physics and Computation Group (FPC) is contributing new theories, models, and computational tools for accurate engineering design analysis and control of complex flows (including acoustics, chemical reactions, interactions with electromagnetic waves, plasmas, and other phenomena) of interest in aerodynamics, electronics cooling, environment engineering, materials processing, planetary entry, propulsion and power systems, and other areas. A significant emphasis of FPC research is on modeling and analysis of physical phenomena in engineering systems. FPC students and research staff are developing new methods and tools for generation, access, display, interpretation and post-processing of large databases resulting from numerical simulations of physical systems. Research in FPC ranges from advanced simulation of complex turbulent flows to active flow control. The FPC faculty teach graduate and undergraduate courses in acoustics, aerodynamics, computational fluid mechanics, computational mathematics, fluid mechanics, combustion, and thermodynamics and propulsion.

The Mechanics and Computational Group covers biomechanics, continuum mechanics, dynamics, experimental and computational mechanics, finite element analysis, fluid dynamics, fracture mechanics, micromechanics, nanotechnology, and simulation based design. Qualified students can work as research project assistants, engaging in thesis research in working association with the faculty director and fellow students. Projects include analysis, synthesis, and control of systems; biomechanics; flow dynamics of liquids and gases; fracture and micromechanics, vibrations, and nonlinear dynamics; and original theoretical, computational, and experimental investigations in the strength and deformability of elastic and inelastic elements of machines and structures.

The Thermosciences Group conducts experimental and analytical research on both fundamental and applied topics in the general area of thermal and fluid systems. Research strengths include high Reynolds number flows, microfluidics, combustion and reacting flows, multiphase flow and combustion, plasma sciences, gas physics and chemistry, laser diagnostics, microscale heat transfer, convective heat transfer, and energy systems. Research motivation comes from applications including air-breathing and space propulsion, bioanalytical systems, pollution control, electronics fabrication and cooling, stationary and mobile energy systems, biomedical systems, and materials processing. There is a strong emphasis on fundamental experiments leading towards advances in modeling, optimization, and control of complex systems.

*Mission Statement*—The goal of Stanford's undergraduate program in Mechanical Engineering is to provide each student with a balance of intellectual and practical experiences, accumulation of knowledge, and self-discovery in order to prepare the graduate to address a variety of societal needs. The program prepares each student for entry-level work as a mechanical engineer, for graduate study in engineering, or for graduate study in another field where a broad and fundamental engineering background provides a desirable foundation. With solid grounding in the principles and practice of mechanical engineering, graduates are ready to engage in a lifetime of learning about and employing new concepts, technologies, and methodologies, whatever their ultimate career choice.

## FACILITIES

The department groups maintain modern laboratories that support undergraduate and graduate instruction and graduate research work.

The Structures and Composites Laboratory, a joint activity with the Department of Aeronautics and Astronautics, studies structures made of fiber-reinforced composite materials. Equipment for fabricating structural elements include autoclave, filament winder, and presses. X-ray, ultrasound, and an electron microscope are available for nondestructive testing. The lab also has environmental chambers, a high speed impactor, and mechanical testers. Lab projects include designing composite structures, developing novel manufacturing processes, and evaluating environmental effects on composites.

Experimental facilities are available through the interdepartmental Structures and Solid Mechanics Research Laboratory, which includes an electrohydraulic materials testing system, a vehicle crash simulator, and a shake table for earthquake engineering and related studies, together with highly sophisticated auxiliary instrumentation. Facilities to study the micromechanics of fracture areas are available in the Micromechanics/Fracture Laboratory, and include a computer controlled materials testing system, a long distance microscope, an atomic force microscope, and other instrumentation. Additional facilities for evaluation of materials are available through the Center for Materials Research, Center for Integrated Circuits, and the Ginzton Laboratory. Laboratories for biological experimentation are available through the School of Medicine. Individual accommodation is provided for the work of each research student.

Major experimental and computational laboratories engaged in bioengineering work are located in the Biomechanical Engineering Group. Other Biomechanical Engineering Group activities and resources are associated with the Rehabilitation Research and Development Center of the Veterans Administration Palo Alto Health Care System. This major national research center has computational and prototyping facilities. In addition, the Rehabilitation Research and Development Center houses the Electrophysiology Laboratory, Experimental Mechanics Laboratory, Human Motor Control Laboratory, Rehabilitation Device Design Laboratory, and Skeletal Biomechanics Laboratory. These facilities support graduate course work as well as Ph.D. student research activities.

Computational and experimental work is also conducted in various facilities throughout the School of Engineering and the School of Medicine, particularly the Advanced Biomaterials Testing Laboratory of the Department of Materials Science and Engineering, the Orthopaedic Research Laboratory in the Department of Functional Restoration, and the Vascular Research Laboratory in the Department of Surgery. In collaboration with the School of Medicine, biologically and clinically oriented work is conducted in various facilities throughout the Stanford Medical Center and the Veterans Administration Palo Alto Health Care System.

The Design Group has facilities for lab work in experimental mechanics and experimental stress analysis. Additional facilities, including MTS electrohydraulic materials test systems, are available in the Solid Mechanics Research Laboratory. Design Group students also have access to Center for Integrated Systems (CIS) and Ginzton Lab microfabrication facilities.

The group also maintains the Product Realization Laboratory (PRL) a teaching facility offering students integrated experiences in market definition, product design, and prototype manufacturing. The PRL provides coaching, design and manufacturing tools, and networking opportunities to students interested in product development. The ME 310 Design Project Laboratory has facilities for CAD, assembly, and testing of original designs by master's students in the engineering design program. A Smart Product Design Laboratory supports microprocessor application projects. The Center for Design Research (CDR) has an excellent facility for concurrent engineering research, development, and engineering curriculum creation and assessment. Resources include a network of high-performance workstations. For worldwide web mediated concurrent engineering by virtual, non-collocated, design development teams, see the CDR web site at http://cdr.stanford.edu. In addition, CDR has several industrial robots for student projects and research. These and several NC machines are part of the CDR Manufacturing Sciences Lab. The Manufacturing Modeling Laboratory (MML) addresses various models and methods that lead to competitive manufacturing. MML links design for manufacturing (dfM) research at the Department of Mechanical Engineering with supply chain management activities at the Department of Management Science and Engineering. The Rapid Prototyping Laboratory consists of seven processing stations including cleaning, CNC milling, grit blasting, laser deposition, low temperature deposition, plasma deposition, and shot peening. Students gain experience by using ACIS and Pro Engineer on Hewlett Packard workstations for process software development. The Design Group also has a unique "Product Design Loft," in which students in the joint program in Design develop graduate thesis projects.

The Flow Physics and Computation Group has a 32 processor Origin 2000, a 48-node and 85-node Linux clusters with high performance interconnection and an array of powerful workstations for graphics and data analysis. Several software packages are available, including all the major commercial CFD codes. FPC is strongly allied with the Center for Turbulence Research (CTR), a research consortium between Stanford and NASA, and the Center for Integrated Turbulence Simulations (CITS), which is supported by the Department of Energy (DOE) under its Accelerated Strategic Computing Initiative (ASCI). The Center for Turbulence Research has direct access to major national computing facilities located at the nearby NASA-Ames Research Center, including massively parallel super computers. The Center for Integrated Turbulence Simulations has access to DOE's vast supercomputer resources. The intellectual atmosphere of the Flow Physics and Computation Group is greatly enhanced by the interactions among CTR's and CITS's staff of post-doctoral researchers and distinguished visiting scientists.

The Mechanics and Computation Group has a Computational Mechanics Laboratory that provides an integrated computational environment for research and research-related education in computational mechanics and scientific computing. The laboratory houses Silicon Graphics, Sun, and HP workstations and servers, including an 8-processor SGI Origin2000 and a 16-processor networked cluster of Intel-architecture workstations for parallel and distributed computing solutions of computationally intensive problems. A wide spectrum of software is available on the laboratory machines, including major commercial packages for engineering analysis, parametric geometry and meshing, and computational mathematics. The laboratory supports basic research in computational mechanics as well as the development of related applications such as simulation-based design technology.

The Thermosciences Group has four major laboratory facilities. The Heat Transfer and Turbulence Mechanics Laboratory concentrates on fundamental research aimed at understanding and improved prediction of turbulent flows and high performance energy conversion systems. The laboratory includes two general purpose wind tunnels, a pressurized high Reynolds number tunnel, two supersonic cascade flow facilities, three specialized boundary layer wind tunnels, and several other flow facilities. Extensive diagnostic equipment is available including multiple particle-image velocimetry and laser-Doppler anemometry systems.

The High Temperature Gas Dynamics Laboratory includes research on sensors, plasma sciences, cool and biomass combustion and gas pollutant formation, and reactive and non-reactive gas dynamics. The experimental capability of the diagnostic devices for combustion gases, a spray combustion facility, laboratory combustors including a coal combustion facility and supersonic combustion facilities, several advanced laser systems, a variety of plasma facilities, a pulsed detonation facility, and four shock tubes and tunnels. The Thermosciences Group and the Design Group share the Microscale Thermal and Mechanical Characterization laboratory (MTMC). MTMC is dedicated to the measurement of thermal and mechanical properties in thin-film systems, including microfabricated sensors and actuators and integrated circuits, and features a nanosecond scanning laser thermometry facility, a laser interferometer, a near-field optical microscope, and an atomic force microscope. The activities at MTMC are closely linked to those at the Heat Transfer Teaching Laboratory (HTTL), where undergraduate and master's students use high-resolution probe stations to study thermal phenomena in integrated circuits and thermally-actuated microvalves. HTTL also provides macroscopic experiments in convection and radiative exchange.

The Energy Systems Laboratory is a teaching and research facility dedicated to the study of energy conversion systems. The lab includes three dynamometers for engine testing, a computer-controlled variable engine valve controller, a fuel-cell experimental station, a small rocket testing facility, and a small jet engine thrust stand.

The Guidance and Control Laboratory, a joint activity with the Department of Aeronautics and Astronautics and the Department of Mechanical Engineering, specializes in construction of electromechanical systems and instrumentation, particularly where high precision is a factor. Work ranges from robotics for manufacturing to feedback control of fuel injection systems for automotive emission control. The faculty and staff work in close cooperation with both the Design and Thermosciences Groups on device development projects of mutual interest.

Many computation facilities are available to department students. Three of the department's labs are equipped with super-minicomputers. Numerous smaller minicomputers and microcomputers are used in the research and teaching laboratories.

Library facilities at Stanford are outstanding. In addition to the general library, there are Engineering, Mathematics, Physics, and other department libraries of which engineering students make frequent use.

## UNDERGRADUATE PROGRAMS

### BACHELOR OF SCIENCE

Specializing in mechanical engineering (ME) during the undergraduate period may be done by following the curriculum outlined earlier under the "School of Engineering" section of this bulletin. The University's basic requirements for the bachelor's degree are discussed in the "Undergraduate Degrees" section of this bulletin. Courses taken for the departmental major (math; science; science, technology, and society; engineering fundamentals; and engineering depth) must be taken for a letter grade if the instructor offers the option.

A Product Design program is offered by the Design Group and leads to the B.S. Engineering (Product Design). An individually designed major in Biomechanical Engineering (B.S.E.: Biomechanical Engineering), offered by the Biomechanical Engineering Group, may be appropriate for some students preparing for medical school or graduate bioengineering studies.

*Grade Requirements*—To be recommended by the department for a B.S. in Mechanical Engineering, a student must achieve the minimum grade point average (GPA) set by the School of Engineering (2.0 in engineering fundamentals and engineering depth).

For information about an ME minor, see the "School of Engineering" section of this bulletin.

## HONORS PROGRAM

The Department of Mechanical Engineering offers a program leading to a B.S. in Mechanical Engineering with honors. This program offers a unique opportunity for qualified undergraduate engineering majors to conduct independent study and research at an advanced level with a faculty mentor.

Mechanical Engineering majors who have a grade point average (GPA) of 3.5 or higher in the major may apply for the honors program. Students who meet the eligibility requirement and wish to be considered for the honors program must submit a written application to the Mechanical Engineering student services office no later than the second week of the Autumn Quarter in the senior year. The application to enter the program can be obtained from the ME student services office, and must contain a one-page statement describing the research topic and include a transcript of courses taken at Stanford. In addition, the application is to be approved by a Mechanical Engineering faculty member who agrees to serve as the thesis adviser for the project. Thesis advisers must be members of Stanford's Academic Council.

In order to receive department honors, students admitted to the program must:

1. maintain the 3.5 GPA required for admission to the honors program.
2. under the direction of the thesis adviser, complete at least 9 units of ME 191H, Honors Thesis, during the senior year.
3. submit a completed thesis draft to the adviser by mid-May. Further revisions and final endorsement by the adviser are to be finished by the first week of June, when two bound copies are to be submitted to the Mechanical Engineering student services office.
4. present the thesis at the Mechanical Engineering Honors Symposium held in mid-May.

## COTERMINAL B.S./M.S. PROGRAM

Stanford undergraduates who wish to continue their studies for the Master of Science degree in the coterminal program must have earned a minimum of 120 units towards graduation. This includes allowable Advanced Placement (AP) and transfer credit. Applicants must submit their application no later than the quarter prior to the expected completion of their undergraduate degree. This is normally the Winter Quarter (January 15 is the deadline) prior to the Spring Quarter graduation. The application must provide evidence of potential for strong academic performance as a graduate student. The application is evaluated and acted on by the graduate admissions committee of the department. Typically, a GPA of at least 3.5 in engineering, science, and math is expected. Applicants must have completed two of 80, 112, 113, 131A, and 131B, and must take the Graduate Record Examination (GRE) before action is taken on the application. Product designers must have completed ME 116 to be considered, and are required to work at least one year before rejoining the program. Coterminal information, applications deadlines, and forms can be obtained from the ME student services office.

For University coterminal degree program rules and University application forms, see http://registrar.stanford.edu/publications/#Coterm.

# GRADUATE PROGRAMS

## ADMISSION AND FINANCIAL ASSISTANCE

To be eligible for admission to the department, a student must have a B.S. degree in engineering (the Ph.D. degree requires the completion of the M.S.), physics, or a comparable science program. Applications for all degree programs are accepted throughout the year, although applications for fellowship aid must be received by December 5. The department annually awards, on a competitive basis, a limited number of fellowships, teaching assistantships, and research assistantships to incoming graduate students. Research assistantships are used primarily for post-master's degree students and are awarded by individual faculty research supervisors, not by the department.

Mechanical engineering is a varied profession, ranging from primarily aesthetic aspects of design to highly technical scientific research. Discipline areas of interest to mechanical engineers include biomechanics, energy conversion, fluid mechanics, materials, nuclear reactor engineering, propulsion, rigid and elastic body mechanics, systems engineering, scientific computing, and thermodynamics, to name a few. No mechanical engineer is expected to have a mastery of the entire spectrum.

Master's degree programs are offered in Mechanical Engineering (M.S.:ME), Engineering (Biomechanical Engineering, M.S.E.:BME), Engineering (Product Design, M.S.E.:PD), and Engineering (M.S.E.).

The following sections list specific requirements for the master's degrees listed above.

## MASTER OF SCIENCE

The basic University requirements for the M.S. degree are discussed in the "Graduate Degrees" section of this bulletin.

The master's program consists of 45 units of course work taken at Stanford. No thesis is required, although many students become involved in research projects during the master's year, particularly to explore their interests in working for the Ph.D. degree. Students whose undergraduate backgrounds are entirely devoid of some of the major subject disciplines of engineering (for example, applied mechanics, applied thermodynamics, fluid mechanics, ordinary differential equations) may need to take some undergraduate courses to fill in obvious gaps and prepare themselves to take graduate courses in these areas. Such students may require more than three quarters to fulfill the master's degree requirements, as the makeup courses may not be used for other than the unrestricted electives (see item 4 below) in the M.S. degree program. However, it is not the policy to require fulfillment of mechanical engineering B.S. degree requirements in order to obtain an M.S. degree; furthermore, students who have already fulfilled certain categories of the M.S. degree requirements as a result of undergraduate work may find they have sufficient time (see item 3 below) to obtain the M.S. degree in the three quarters.

### MECHANICAL ENGINEERING

The master's degree program requires 45 units of course work taken as a graduate student at Stanford. No thesis is required. However, students who desire some research experience during the master's year may participate in research through ME 391 and 392.

The department's requirements for the M.S. in Mechanical Engineering are:

1. *Mathematical Competence in Two of the Following Areas:* partial differential equations, linear algebra, complex variables, or numerical analysis, as demonstrated by completion of two appropriate courses from the following list: ME 300A,B,C; MATH 106, 109; CS 205; EE 263, 261; STATS 110, ENGR 155C; CS 237A,B (requirement 6 units).

   Students who completed comparable graduate-level courses as an undergraduate, and who can demonstrate their competence to the satisfaction of the instructors of the Stanford courses, may be exempted from this requirement by their adviser *and* the Graduate Curriculum Committee, and place the units in the approved elective category.
2. *Specialty in Mechanical Engineering (Depth):* set of graduate-level courses in Mechanical Engineering to provide depth in one area. These sets have been approved by the faculty as providing depth in specific areas as well as a significant component of applications of the material in the context of engineering synthesis. These sets are outlined in the *Mechanical Engineering Handbook* at http://me.stanford.edu.
3. *Breadth in Mechanical Engineering:* two additional graduate level courses (outside the depth) from the breadth chart listed in the *Mechanical Engineering Graduate Handbook* to bring the total number of ME units to at least 18.
4. *Approved Electives* (to bring the total number of units to 39): all these units must have adviser approval. Graduate engineering, math, and science courses are normally approved. Of the 39 units, no more than 6 may come from ME 391 and 392, and no more than 3 may come from seminars. Students planning a Ph.D. degree should discuss with their adviser the desirability of taking 391 or 392 during the master's year.
5. *Unrestricted Electives* (to bring the total number of units submitted for the M.S. degree to 45): students are encouraged to use these units

outside of engineering, mathematics, or the sciences. Students should consult their advisers on course loads and on ways to use the unrestricted electives to make a manageable program.

6. Within the courses satisfying the requirements above, there must be at least one graduate-level course dealing with lab studies. Courses which satisfy this requirement are 218A, 306A, 307B, 318, 310A,B,C, 317B, 324, 348, 354, 367, 382A,B.

Candidates for the M.S. in Mechanical Engineering are expected to have the approval of the faculty, and a minimum grade point average (GPA) of 2.75 in the 45 units presented in fulfillment of degree requirements. All courses used to fulfill depth, breadth, approved electives, and lab studies must be graded (excluding seminars and courses for which a Satisfactory/No Credit grade is given to all students).

Students falling below a GPA of 2.5 at the end of 20 units may be disqualified from further registration. Students failing to meet the complete degree requirements at the end of 60 units of graduate registration are disqualified from further registration. Courses used to fulfill deficiencies arising from inadequate undergraduate preparation for mechanical engineering graduate work may not be applied to the 60 units required for graduate registration.

### PRODUCT DESIGN

The Joint Program in Design focuses on the synthesis of technology with human needs and values to create innovative product experiences. This program is a joint offering of the departments of Mechanical Engineering and Art and Art History. It provides a design education that integrates technical, human, aesthetic, and business concerns. The resulting two-year degree of M.S. in Engineering (Product Design) is considered a terminal degree for the practice of design.

| *Course No. and Subject* | *Units* |
|---|---|
| ARTSTUDI 60. Design I: Fundamental Visual Language | 3 |
| ARTSTUDI 160. Design II: The Bridge | 3 |
| ME203. Manufacturing and Design | 4 |
| ME216A. Advanced Product Design: Needfinding | 4 |
| ME216B. Advanced Product Design: Implementation | 4 |
| ME312. Advanced Product Design: Formgiving | 4 |
| ME313. Human Value and Innovation in Design | 3 |
| ME316ABC.* Product Design Master's Project | 12 |
| ARTSTUDI 360A,B,C* Master's Project | 6 |
| Approved Electives† | 17 |

* ME316A,B,C and ARTSTUDI 360A,B,C are taken concurrently for three quarters during the second year.

† Approved electives fulfill career objectives of the students. Students may focus their energy in engineering, business, psychology, or other areas relevant to design. Most students elect a broad approach that spans these domains and increases their cultural awareness. Approved electives must be discussed with the student's adviser.

Admission requirements are the same as for the M.S.:ME described above, with the additional requirements of a minimum of one year's experience after the bachelor's degree, and a portfolio showing strong evidence of design ability and aesthetic skills and sensitivity.

Students with non-engineering undergraduate degrees in design, art, architecture, and so on, may apply to the Department of Art and Art History for a similar graduate design program administered by that department and leading to an M.F.A. in Design. Students with non-engineering degrees who wish to earn the M.S. degree should consult with the program adviser.

### BIOMECHANICAL ENGINEERING

Students interested in graduate studies in biomechanical engineering can choose one of the programs below.

1. *M.S. in Mechanical Engineering:* students who apply and are admitted to the M.S.:ME program can elect to take biomechanical engineering courses as part of their M.S.:ME requirements. These courses are usually applied towards the student's engineering breadth or technical electives.
2. *M.S. in Engineering: Biomechanical Engineering* (M.S.E.:BME): this degree program allows students more flexibility in taking courses in the life sciences and generally emphasizes a more interdisciplinary curriculum. Minimum grade point average (GPA) requirements are the same as for the M.S. in Mechanical Engineering.

A Ph.D. in Biomechanical Engineering is not given. Students from either master's degree path (Mechanical Engineering or Biomechanical Engineering) receive their Ph.D. degrees in Mechanical Engineering.

### ENGINEERING

As described in the "School of Engineering" section of this bulletin, each department in the school may sponsor students in a more general degree, the M.S. in Engineering. Sponsorship by the Department of Mechanical Engineering (ME) requires (1) filing a petition for admission to this program on the day before instruction begins, and (2) that the center of gravity of the proposed program lies in ME; no more than 18 units used for the proposed program can have been previously completed. The program must include at least 9 units of graduate-level work in the department other than ME 300A,B,C, seminars, and independent study. The petition must be accompanied by a statement explaining the program objectives and how it is coherent, contains depth, and fulfills a well defined career objective. The grade requirements are the same as for the M.S. in Mechanical Engineering.

## POST-MASTER'S DEGREE PROGRAMS

The department offers two post-master's degrees: Engineer and Doctor of Philosophy. Post-master's research generally requires some evidence that a student has research potential before a faculty member agrees to supervision and a research assistantship. It is most efficient to carry out this preliminary research effort during the M.S. degree year.

### ENGINEER

The basic University requirements for the degree of Engineer are discussed in the "Graduate Degrees" section of this bulletin.

This degree represents an additional year of study beyond the M.S. degree and includes a research thesis. The program is designed for students who wish to do professional engineering work upon graduation and who want to engage in more specialized study than is afforded by the master's degree alone.

Admission standards are substantially the same as indicated under the master's degree. However, since thesis supervision is required and the availability of thesis supervisors is limited, admission is not granted until the student has personally engaged a faculty member to supervise a research project. This frequently involves a paid research assistantship awarded by individual faculty members (usually from the funds of sponsored research projects under their direction) and *not* by the department. Thus, personal arrangement is necessary. Students studying for the M.S. degree at Stanford and desiring to continue to the Engineer degree ordinarily make such arrangements during the M.S. degree year. Students holding master's degrees from other universities are invited to apply and may be admitted providing they are sufficiently well qualified and have made thesis supervision and financial aid arrangements.

Department requirements for the degree include an acceptable thesis; up to 18 units of credit are allowed for thesis work. In addition to the thesis, 27 units of approved advanced course work in mathematics, science, and engineering are expected beyond the requirements for the M.S. degree; the choice of courses is subject to approval of the adviser. Students who have not fulfilled the Stanford M.S. degree requirements are required to do so (with allowance for approximate equivalence of courses taken elsewhere).

Candidates for the degree must have faculty approval and have a minimum grade point average (GPA) of 3.0 for all courses (exclusive of thesis credit) taken beyond those required for the master's degree.

### DOCTOR OF PHILOSOPHY

The basic University requirements for the Ph.D. degree are discussed in the "Graduate Degrees" section of this bulletin. The Ph.D. degree is intended primarily for students who desire a career in research, advanced development, or teaching; for this type of work, a broad background in math and the engineering sciences, together with intensive study and research experience in a specialized area, are the necessary requisites.

The department allows a minor field but does not require one. However, if a minor is waived, the candidate must show breadth of training by taking courses in one or more related fields or departments as noted below.

A student studying for the Ph.D. degree ordinarily does not take an Engineer degree, although this is not precluded. However, the student must have a master's degree, and must fulfill in essence the requirements for the Stanford M.S. degree in Mechanical Engineering.

In special situations dictated by compelling academic reasons, Academic Council members who are not members of the department's faculty may serve as the principal dissertation adviser when approved by the department. In such cases, a member of the department faculty must serve as program adviser and as a member of the reading committee, and agree to accept responsibility that department procedures are followed and standards maintained.

Admission involves much the same consideration described under the Engineer degree. Since thesis supervision is required, admission is not granted until the student has personally engaged a member of the faculty to supervise a research project. Once a student has obtained a research supervisor, this supervisor becomes thereafter the student's academic adviser. Research supervisors may require that the student pass the departmental oral examination before starting research and before receiving a paid research assistantship. Note that research assistantships are awarded by faculty research supervisors and *not* by the department.

Prior to being formally admitted to candidacy for the Ph.D. degree, the student must demonstrate knowledge of engineering fundamentals by passing a qualifying oral examination. The academic level and subject matter of the examination correspond approximately to the M.S. program described above.

Typically, the exam is taken shortly after the student earns a master's degree. The student is expected to have a nominal graduate Stanford GPA of 3.5 to be eligible for the exam. Once the student's faculty sponsor has agreed that the exam is to take place, the student must submit an application folder containing several items including a curriculum vitae, research project abstract, and preliminary dissertation proposal. Information and examination dates may be obtained from the department's student services office.

Ph.D. candidates must complete a minimum of 27 units of approved formal course work (excluding research, directed study, and seminars) in advanced study beyond the M.S. degree. The courses should consist primarily of graduate courses in engineering and sciences, although the candidate's reading committee may approve a limited number of upper-level undergraduate courses and courses outside of engineering and sciences, as long as such courses contribute to a strong and coherent program. In addition to this 27-unit requirement, all Ph.D. candidates must participate each quarter in one of the following (or equivalent) seminars: ME 389, 390, 394, 395, 396 397; ENGR 311A,B, 298; AA 296 or 297.

The Ph.D. thesis normally represents at least one full year of research work and must be a substantial contribution to knowledge. Students may register for course credit for thesis work (ME 500) to help fulfill University academic unit requirements, but there is no minimum limit on registered dissertation units. Candidates should note that only completed course units are counted toward the requirement. Questions should be directed to the department manager of student services.

The department has a breadth requirement for the Ph.D. degree. This may be satisfied either by a formal minor in another department or by course work that is approved by the dissertation reading committee.

The final University oral examination is conducted by a committee consisting of a chair from another department and four faculty members of the department or departments with related interests. Usually, the committee includes the candidate's adviser and two faculty members chosen to read and sign the candidate's dissertation. The examination consists of two parts. The first is open to the public and is scheduled as a seminar talk, usually for one of the regular meetings of a seminar series. The second is conducted in private and covers subjects closely related to the dissertation topic.

#### PH.D. MINOR

Students who wish a Ph.D. minor in ME should consult the ME student services office. A minor in ME may be obtained by completing 20 units of approved graduate-level ME courses. Courses approved for the minor must form a coherent program and must be selected from those satisfying requirement 2 for the M.S. in Mechanical Engineering.

## COURSES

WIM indicates that the course satisfies the Writing in the Major requirements. (AU) indicates that the course is subject to the University Activity Unit limitations (8 units maximum).

The department uses the following course numbering system:

010-099 Freshman and Sophomore
100-199 Junior and Senior
200-299 Advanced Undergraduate and Beginning Graduate
300-399 Graduate
400-499 Advanced Graduate
500 Ph.D Thesis

## UNDERGRADUATE (FRESHMEN AND SOPHOMORES)

*Note*—Lab sections in experimental engineering are assigned in groups. If the lab schedule permits, students are allowed, with due regard to priority of application, to arrange their own sections and lab periods. Enrollment with the instructor concerned, on the day before instruction begins or the first day of University instruction, is essential in order that the lab schedule may be prepared. Enrollment later than the first week is not permitted.

**ME 13N. Designing the Human Experience**—Stanford Introductory Seminar. (Formerly 73N.) Preference to freshmen. The theory and practice of design thinking: the proposition that design thinking is liberal art. Hands-on work with an external, real-world client. GER:2b
*3-5 units, Aut (Leifer)*

**ME 16N. The Science of Flames**—Stanford Introductory Seminar. (Formerly 76N.) Preference to freshmen. The roles that chemistry and fluid dynamics play in governing the behaviors of flames. Emphasis is on factors that affect flame microstructure, external appearance, and on the fundamental physical and chemical processes that cause flames and fires to propagate. Topics: history, thermodynamics, and pollutant formation in flames. Trips to labs where flames are studied. Prerequisites: high school physics and an interest in thermochemical phenomena. GER:2b
*3 units, Spr (Mitchell)*

**ME 17N. Robotic Animals**—Stanford Introductory Seminar. Preference to freshmen. The idea of constructing robots that duplicate the functional abilities of humans and/or other animals has been promulgated primarily by science fiction writers; biological systems provide models for designers of the mechanical, electrical, and information systems of robots. Building electromechanical devices that perform locomotory and sensing functions similar to those of an animal is a way of learning about the ways biological systems function. Walking and running machines, and the problem of giving a robot the capability to respond to its environment. GER:2b
*3 units, Aut (Waldron)*

**ME 18Q. Creative Teams and Individual Development**—Stanford Introductory Seminar. Preference to sophomores. Students learn what roles on a problem solving team best suit individual creative characteristics. Two teams are formed for teaching experientially how to develop less conscious abilities from teammates creative in those roles. Reinforcement teams have members with similar personalities; problem solving teams are composed of people with maximally different personalities. GER:2b
*3 units, Aut (Wilde)*

**ME 21N. Human and Machine Haptics**—Stanford Introductory Seminar. Preference to freshmen. Touch and force feedback elements of human/machine interaction with applications including video games and robot-assisted surgery. Do haptics have the potential to rival vision and sound in future computer applications. The biology of human touch and tactile perception; technologies that can be used for conveying a sense of touch to human beings interacting with computer-controlled systems. Demonstrations of applications in robotics, medicine, gaming, and virtual reality. Future systems with immersive haptic feedback; what technological advances are needed to make them practical. GER:2b
*3 units, Win (Cutkosky)*

**ME 70. Introductory Fluids Engineering**—Elements of fluid mechanics as applied to engineering problems. Equations of motion for incompressible ideal flow. Hydrostatics. Control volume laws for mass, momentum, and energy. Bernoulli equation. Dimensional analysis and similarity. Flow in ducts. Boundary layer flows. Lift and drag. Lab demonstration experiments are related to course material. Limited enrollment Spring Quarter. When possible, register for Winter Quarter. Prerequisites: ENGR 14 and 30. GER:2b
*4 units, Win (Mungal), Spr (Santiago)*

**ME 80. Stress, Strain, and Strength**—The basic mechanics of materials and engineering properties of structural materials. Topics include static failure theories for ductile and brittle materials, stress concentrations, and buckling. Fracture, fatigue, corrosion, fretting, and wear. Failure in structural components emphasizing applications to mechanical design. Experiment and design component addresses characterization of real materials and structures. Prerequisite: ENGR 14. GER:2b
*4 units, Aut (Pruitt)*

## UNDERGRADUATE (JUNIORS AND SENIORS)

**ME 101. Visual Thinking**—Lecture/lab. Visual thinking and language skills are developed and exercised in the context of solving design problems. Exercises for the mind's eye. Quickly executed diagrammatic, orthographic, perspective, and three-dimensional sketching with emphasis on fluent and flexible idea production. The relationship between visual thinking and the creative process. Enrollment limited to 60. GER:2b
*3 units, Aut, Win, Spr (Staff)*

**ME 102. Design Improv**—Improvisational techniques and exercises explore topics relating to personal and group design processes and broader cultural issues in product design. The former include personal creative habits, team building, communication, cooperation and team work. Cultural issues include proxemics, status, product-user interaction, and the role of narrative in creating meaning. Prerequisite: enrollment in Product Design or consent of instructor. GER:2b
*3 units, Win (Ryan)*

**ME 103D. Engineering Drawing and Design**—Designed to accompany 203. The fundamentals of engineering drawing including orthographic projection, dimensioning, sectioning, exploded and auxiliary views, and assembly drawings. Homework drawings are of parts fabricated by the student in the shop. Assignments in 203 supported by material in 103D and sequenced on the assumption that the student is enrolled in both courses simultaneously.
*1 unit, Aut, Win (Milroy)*

**ME 105. Feedback Control Design**—(Enroll in ENGR 105.)
*3 units, Win (Rock)*

**ME 110A. Design Sketching**—Freehand sketching, rendering, and design development. Work is guided by instructors. Concurrent assignments in 115 and 216B,C provide subject matter, but the class is open to anyone wishing to improve freehand drawing skills. (AU)
*1 unit, Win, Spr (Staff)*

**ME 110B. Advanced Design Sketching**—Freehand sketching, rendering, design development, and some computer use. Work is guided by instructors. Concurrent assignments in 116 provide subject matter. Prerequisite: 110A or consent of instructor based on drawing skill. (AU)
*1 unit, Aut (Staff)*

**ME 112. Mechanical Engineering Design**—Fundamental characteristics of machine elements including gears, bearings, and shafts. Design for fatigue life. Electric motor fundamentals. Transmission design for maximizing output power or efficiency. Mechanism types, linkage analysis and kinematic synthesis. Team-based design projects emphasizing the balance of physical with virtual prototyping based on engineering analysis. Lab for dissection of mechanical systems and project design reviews. Prerequisites: 80, 101. Recommended: 203, ENGR 15. GER:2b
*4 units, Win (Gerdes)*

**ME 113. Mechanical Engineering Design**—Goal is to create designs and models of new mechanical devices. Design is experienced by students as they work on a team design project obtained from industry or other organizations. Prerequisites: 80, 101, 112. GER:2b
*4 units, Spr (Nelson)*

**ME 115. Human Values in Design**—Active encounters with human values in design. Lectures survey the central philosophy of the product design program, emphasizing the relation between technical and human values, the innovation process, and design methodology. Lab exercises include development of simple product concepts visualized in rapidly executed three-dimensional mockups. Prerequisite: 101. GER:2b
*3 units, Win (Boyle)*

**ME 116. Advanced Product Design: Formgiving**—Small- and medium-scale design projects are carried to a high degree of aesthetic refinement. Emphasis is on generating appropriate forms to the task and setting. Prerequisites: 115, ARTHIST 160. GER:2b
*3-4 units, Aut (Moggridge)*

**ME 120. History and Philosophy of Design**—Major schools of 19th- and 20th-century design (Arts-and-Crafts movement, Bauhaus, Industrial Design, and postmodernism) are analyzed in terms of their continuing cultural relevance. The relation of design to art, technology, and politics; readings from principal theorists, practitioners, and critics; recent controversies in industrial and graphic design, architecture, and urbanism. Enrollment limited to 40. GER:2b
*3-4 units, Spr (Katz)*

**ME 121. Design and Construction in Wood**—(Formerly 195.) The design and construction of objects using wood. Taught in the Product Realization Lab. Enrollment limited.
*1-3 units, Spr (Milroy)*

**ME 131A. Heat Transfer**—Principles of heat transfer by conduction, convection, and radiation; examples from engineering of practical devices and systems. Topics include transient and steady conduction, conduction by extended surfaces, boundary layer theory for forced and natural convection, boiling, heat exchangers, and graybody radiative exchange. Prerequisites: 70, ENGR 30. Recommended: intermediate calculus, ordinary differential equations. GER:2b
*3-4 units, Aut (Goodson)*

**ME 131B. Fluid Mechanics: Compressible Flow and Turbomachinery**—Engineering applications involving compressible flow: aircraft propulsion, rocket propulsion, power generation; application of mass, momentum, energy and entropy balance to compressible flows; variable area isentropic flow, normal shock waves, adiaba tic flow with friction, flow with heat addition. Flow system operation: the propulsion system. Turbomachinery: pumps, compressors, turbines. Angular momentum analysis of turbomachine performance, centrifugal and axial flow machines, effect of blade geometry, dimensionless performance of turbomachines; hydraulic turbines; steam turbines; wind turbines. Compressible flow turbomachinery: the aircraft engine. Prerequisites: 70, ENGR 30. GER:2b
*3 units, Win (Bowman)*

**ME 140. Advanced Thermal Systems**—Capstone course in thermal science, providing experience in thermal analysis and engineering, with emphasis on integrating heat transfer, fluid mechanics, and thermodynamics into a unified approach to treating complex systems. Lecture introduces mixtures, humidity, chemical and phase equilibrium, and availability. Labs apply principles through hands-on experience with a turbojet engine, a PEM fuel cell, and a hybrid solid/oxygen rocket motor. Analysis of systems is facilitated using MATLAB as a computational tool. Prerequisites: ENGR 30, ME 70, ME 131A, and ME 131B. GER:2b
*4 units, Spr (Edwards)*

**ME 150. Internal Combustion Engines**—(Formerly 130.) Internal combustion engines including conventional and turbocharged spark ignition, and diesel engines. Lectures: basic engine cycles, engine components, methods of analysis of engine performance, pollutant emissions, and methods of engine testing. Lab involves hands-on experience with engines and test hardware. Limited enrollment. Prerequisites: ME 140. GER:2b

*3 units, Aut (Kaahaaina)*

**ME 161. Dynamic Systems**—Modeling, analysis, and measurement of mechanical and electromechanical systems. Numerical and closed form solutions of ordinary differential equations governing the behavior of single and multiple degree of freedom systems. Stability, resonance, amplification and attenuation, and control system design. Demonstrations and laboratory experiments. Prerequisites: dynamics and calculus such as ENGR 15 and MATH 43. Recommended: CME 102 (formerly ENGR 155A); and differential equations, linear algebra, and basic electronics. Graduate students may enroll with adviser and instructor consent. GER:2b

*4 units, Aut (Mitiguy)*

**ME 191. Engineering Problems and Experimental Investigation**—Directed study and research for undergraduates on a subject of mutual interest to student and staff member. Student must find faculty sponsor and have approval of the adviser.

*1-5 units, Aut, Win, Spr, Sum (Staff)*

**ME 191H. Honors Research**—Student must find faculty honors adviser and apply for admission to the honors program.

*1-5 units, Aut, Win, Spr, Sum (Staff)*

## ADVANCED UNDERGRADUATE AND BEGINNING GRADUATE

**ME 201. Dim Sum of Mechanical Engineering**—Introduction to research in mechanical engineering for M.S. students and upper-division undergraduates. Weekly presentations by current ME Ph.D. students and second-year fellowship students to show research opportunities across the department. Strategies for getting involved in a research project.

*1 unit, Aut (Sheppard, Haccou)*

**ME 203. Manufacturing and Design**—(Formerly 103/303.) Emphasis is on prototype development techniques as an intrinsic part of the design process. Machining, welding, and casting. Manufacturing processes. Design aspects developed in an individual term project chosen, designed, and fabricated by students. Labs, field trips. Undergraduates majoring in Mechanical Engineering or Product Design must take course for 4 units. Limited enrollment with consent of instructor. Corequisite: 103D or drafting experience. Corequisite for WIM for Mechanical Engineering and Product Design majors: Engineering 102M. Recommended: 101. WIM

*3-4 units, Aut, Win (Beach)*

**ME 204. Bicycle Design and Frame-Building**—(Formerly 396.) Emphasis is on engineering and artistic execution of designing and building a bicycle frame. Fundamentals of bicycle dynamics, handling, and sizing. Manufacturing processes. Films, guest lecturers, field trips. Each student designs and fabricates a custom bicycle frame. Limited enrollment. Prerequisite: 203 or equivalent.

*3 units, Spr (Milroy)*

**ME 205. Documenting Your Design Work**—The importance of documenting one's three-dimensional design work in two-dimensional form, using both images and text. Students document and present their own work for peer feedback. Guest lecturers and critiques from professionals in the design field.

*2 units (Staff) not given 2004-05*

**ME 206. Entrepreneurial Design to Eliminate Poverty**—Project course jointly offered by School of Engineering and Graduate School of Business. Students apply engineering and business skills to design product prototypes, distribution systems, and business plans for entrepreneurial ventures in developing countries to for a specified challenge faced by the world's poor. Topics include user empathy, appropriate technology design, rapid prototype engineering and testing, social technology entrepreneurship, business modeling, and project management. Weekly design reviews; final course presentation. Industry and adviser interaction. Limited enrollment via application process; see http://www.stanford.edu/class/me206.

*3 units, Win (Kelley, Patell)*

**ME 207. Negotiation**—(Same as CEE 151/251, MS&E 285.) Introduction to negotiation styles and processes in order to help students conduct and review negotiations. Workshop format integrating intellectual and experiential learning. Students analyze the negotiation process through exercises, live and field examples, individual and small group reviews. Students must apply before the first day of class. See course website for details. Enrollment limited to 50.

*3 units, Aut, Spr (Christensen)*

**ME 210. Introduction to Mechatronics**—(Formerly 118.) The technologies involved in mechatronics (intelligent electro-mechanical systems), and the techniques to apply this technology to mecatronic system design. Topics include electronics (A/D, D/A converters, op-amps, filters, power devices); software program design, event-driven programming; hardware and DC stepper motors, solenoids, and robust sensing. Lab componen of structural assignments. Large and open-ended team project. Limited enrollment. Prerequisites: ENGR 40, CS 106, or equivalent.

*4 units, Win (Kenny, Ohline)*

**ME 216A. Advanced Product Design: Needfinding**—(Formerly 116B/316B.) Human needs that lead to the conceptualization of future products, environments, systems, and services. Field work in public and private settings; appraisal of personal values; readings on social ethnographic issues; and needfinding for a corporate client. Emphasis is on developing the flexible thinking skills that enable the designer to navigate the future. Prerequisite: 115 or consent of instructor.

*3-4 units, Win (Patnaik, Barry)*

**ME 216B. Advanced Product Design: Implementation**—(Formerly 116B/316B.) Summary project utilizing the knowledge, methodology, and skills obtained in 115 and 216A. Students implement design concept and present it to a professional jury. Prerequisite:216A.

*4 units, Spr (Staff)*

**ME 218A. Smart Product Design Fundamentals**—Introduction. Lecture, lab, and design project based series on programmable electromechanical systems design. Topics: transistors as switches, basic digital and analog circuits, boolean algebra, combinatorial and sequential logic, operational amplifiers, comparators, software design, programming in FORTH and C. Team project. Enrollment in 218B,C is contingent on completing 218A or passing a Smart Product Design Fundamentals proficiency examination given at the start of Autumn Quarter. Lab fee. Limited enrollment.

*4-5 units, Aut (Carryer)*

**ME 218B. Smart Product Design Applications**—Intermediate level in the series of programmable electromechanical systems design, introduced in the context of lab assignments and integrated into a team project. Topics: user I/O, timer systems, interrupts, signal conditioning, software design for embedded systems, sensors, actuators, noise, and power supplies. Team project. Lab fee. Limited enrollment. Prerequisite: 218A or passing the smart product design fundamentals proficiency examination.

*4-5 units, Win (Carryer)*

**ME 218C. Smart Product Design Practice**—Advanced level in the series on programmable electromechanical systems design. Topics: inter-processor communication, system design with multiple microprocessors, architecture and assembly language programming for the PIC microcontroller, design with programmable logic, understanding and controlling the embedded software tool chain, A/D and D/A techniques, electronic manufacturing technology. Lab fee. Limited enrollment. Team project. Prerequisite: completion of 218B.

*4-5 units, Spr (Carryer)*

**ME 218D. Smart Product Design: Projects**—Industrially sponsored project is the culmination of the Smart Product Design sequence. Student teams take on an industrial project that requires the application and extension of the knowledge gained in the prior three quarters, including prototyping of a final solution with hardware, software, and professional documentation and presentation. Lectures extend the students' knowledge of electronic and software design, and electronic manufacturing techniques. Topics: chip level design of microprocessor systems, real time operating systems, alternate microprocessor architectures, PCB layout and fabrication.
*4 units, Aut (Carryer)*

**ME 220. Introduction to Sensors**—(Formerly 117/220.) Sensors are widely used in scientific research and as an integral part of commercial products and automated systems. The basic principles for sensing displacement, force, pressure, acceleration, temperature, optical radiation, nuclear radiation, and other physical parameters. Performance, cost, and operating requirements of available sensors. Elementary electronic circuits which are typically used with sensors. Lecture demonstration of a representative sensor from each category elucidates operating principles and typical performance. Lab experiments with off-the-shelf devices.
*3-4 units, Spr (Kenny)*

**ME 222. Beyond Green Theory: A Workshop in Ecological Design**—Goal is to translate green theory into product form through short projects that address materials, product function and co-function, and situational patterns or habits. How to blend ecological design processes with standard design methodologies.
*2-3 units, Spr (Staff)*

**ME 223. Topics in Design**—Topics of current interest. Contents change each quarter. May be repeated for credit.
*2-4 units, Aut, Win, Spr (Staff)*

**ME 227. Vehicle Dynamics and Control**—The application of dynamics, kinematics, and control theory to the analysis and design of ground vehicle behavior. Simplified models of ride, handling, and braking, their role in developing intuition, and limitations in engineering design. Suspension design fundamentals. Performance and safety enhancement through automatic control systems. In-car laboratory assignments for model validation and kinesthetic understanding of dynamics. Limited enrollment. Prerequisite: 161, consent of instructor. Recommended: ENGR 105.
*3 units, Spr (Gerdes)*

**ME 229. Multiscale Methods in Engineering**—(Enroll in CME 210.)
*3 units, Spr (Darve, Donoho)*

**ME 240. Introduction to Nanotechnology**—Nanotechnology is multidisciplinary in nature with contributions from physical sciences, engineering, and business. Current topics in nanotechnology research and developments in nanomaterials, mechanics, electronics, and sensors and applications to provide background, current status, and perspective on future technological progress. Nano-scale materials building blocks, fabrication and assembly processes, characterization and properties, and novel system architectures. Implications for the future development.
*3 units (Cho, Srivastara) not given 2004-05*

**ME 260. Fuel Cell Science Technology**—Emphasis is on proton exchange membrane (PEM) and solid oxide fuel cells (SOFC). Principles of electrochemical energy conversion. Topics in materials science, thermodynamics, and fluid mechanics. Limited enrollment.
*3 units, Aut (O'Hayre)*

**ME 280. Skeletal Development and Evolution**—(Same as BIOE 280; formerly 180.) The mechanobiology of skeletal growth, adaptation, regeneration, and aging is considered from developmental and evolutionary perspectives. Emphasis is on the interactions between mechanical and chemical factors in the regulation of connective tissue biology. Prerequisites: 80, or Human Biology core, or Biological Sciences core. GER:2b
*3 units, Spr (Carter)*

**ME 281. Biomechanics of Movement**—(Same as BIOE 281; formerly 181.) Review of experimental techniques used to study human and animal movement including motion capture systems, EMG, force plates, medical imaging, and animation. The mechanical properties of muscle and tendon, and quantitative analysis of musculoskeletal geometry. Projects and demonstrations emphasize applications of mechanics in sports, orthopedics, neuroscience, and rehabilitation. GER:2b
*3 units, Aut (Delp)*

**ME 283. Biomineralization**—(Formerly 182.) The process of formation and adaptation of mineralized structures formed by organisms, principally animal skeletons. Engineering mineralized tissues. Emphasis is on the interacting influences of phylogenic history, material constraints, mechanical factors, and other ecological and physiological considerations. Skeletal formation processes and the skeletal microstructure and ultrastructure of every animal phylum. The evolutionary aspects of body plan design among the major animal phyla with skeletons.
*2 units (Constantz) alternate years, given 2005-06*

**ME 284A. Cardiovascular Bioengineering**—Bioengineering principles applied to the cardiovascular system. Anatomy of human cardiovascular system, comparative anatomy, and allometric scaling principles. Cardiovascular molecular and cell biology. Overview of continuum mechanics. Form and function of blood, blood vessels, and the heart from an engineering perspective. Normal, diseased, and engineered replacement tissues.
*3-4 units, Aut (Taylor)*

**ME 284B. Cardiovascular Bioengineering**—Continuation of ME 284A. Integrative cardiovascular physiology, blood fluid mechanics, and transport in the microcirculation. Sensing, feedback, and control of the circulation. Overview of congenital and adult cardiovascular disease, diagnostic methods, and treatment strategies. Engineering principles to evaluate the performance of cardiovascular devices and the efficacy of treatment strategies.
*3-4 units, Win (Taylor)*

**ME 285. Mineralization of Bone**—The mechanical properties of bone are dependent largely on mineralization. The relationship between mineralization and bone biomechanics; synthesis of bone's organic matrix and stimuli for its development and morphogenesis; the mechanisms of crystal nucleation and growth; pathological states of bone mineralization with respect to the normal state and processes of bone mineralization. Approaches to increase the mineral content of bone and therapeutic approaches that replace lost bone with synthetic bone materials.
*2 units, Spr (Constantz)*

**ME 294. Medical Device Design**—(Formerly 194/394.) In collaboration with the School of Medicine. Introduction to medical device design for undergraduate and graduate engineering students. Significant design and prototyping. Labs expose students to medical device environments, including hands on device testing and field trips to operating rooms and local device companies. Limited enrollment. Prerequisite: 203.
*3 units, Aut (Milroy, Doshi)*

**ME 299. Practical Training**—Educational opportunities in high technology research and development labs in industry. Qualified graduate students engage in internship work and integrate that work into their academic program. Following internship, work students complete a research report outlining their work activity, problems investigated, key results, and any follow-on projects they expect to perform. Meets the requirements for Curricular Practical Training for Students on F-1 visas. Student is responsible for arranging own employment and faculty sponsorship. Register under faculty sponsor's section number.
*1 unit, Aut, Win, Spr, Sum (Staff)*

## GRADUATE

**ME 300A. Linear Algebra with Application to Engineering Computations**—(Enroll in CME 200.)
*3 units, Aut (Gerritsen)*

**ME 300B. Partial Differential Equations in Engineering**—(Enroll in CME 204.)
*3 units, Win (Lele)*

**ME 300C. Introduction to Numerical Methods for Engineering**—(Enroll in CME 206.)
*3 units, Spr (Farhat)*

**ME 305. Introduction to Control Design Techniques**—(Enroll in ENGR 205.)
*3 units, Aut (Tomlin)*

**ME 305. Engineering Risk Analysis**—(Enroll in MS&E 250A.)
*2-3 units, Win (Paté-Cornell)*

**ME 306A. Control System Design**—(Enroll in ENGR 206.)
*4 units, Spr (Niemeyer)*

**ME 306B. Analysis and Control of Nonlinear Systems**—(Enroll in ENGR 209A.)
*3 units, Win (Tomlin)*

**ME 307A. Modern Control Design I**—(Enroll in ENGR 207A.)
*3 units, Win (Lall)*

**ME 307B. Modern Control Design II**—(Enroll in ENGR 207B.)
*3 units, Spr (Lall)*

**ME 308. Spatial Motion**—The geometry of motion in Euclidean space. Fundamentals of theory of screws with applications to robotic mechanisms, constraint analysis, and vehicle dynamics. Methods for representing the positions of spatial systems of rigid bodies with their interrelationships; the formulation of Newton-Euler kinetics applied to serial chain systems such as industrial robotics.
*3 units, Win (Waldron) alternate years, not given 2005-06*

**ME 309. Finite Element Analysis in Mechanical Design**—Basic concepts of finite elements, with applications to problems confronted by mechanical designers. Linear static, modal, and thermal formulations; nonlinear and dynamic formulations. Students implement simple element formulations. Application of a commercial finite element code in analyzing design problems. Issues: solution methods, modeling techniques features of various commercial codes, basic problem definition. Individual projects focus on the interplay of analysis and testing in product design/development. Prerequisite: MATH 103, or equivalent. Recommended: 80, or equivalent in structural and/or solid mechanics; some exposure to principles of heat transfer.
*3 units (Sheppard) not given 2004-05*

**ME 310A. Tools for Team-Based Design**—(Same as ENGR 310A.) For graduate students; open to limited SITN/global enrollment. Project-based, exposing students to the tools and methodologies for forming and managing an effective engineering design team in a business environment, including product development teams that may be spread around the world. Topics: personality profiles for creating teams with balanced diversity; computational tools for project coordination and management; real time electronic documentation as a critical design process variable; and methods for refining project requirements to ensure that the team addresses the right problem with the right solution. Computer-aided tools for supporting geographically distributed teams. Final project analyzes industry-sponsored design projects for consideration in 310B,C. Investigation includes benchmarking and meetings with industrial clients. Deliverable is a detailed document with project specifications and optimal design team for subsequent quarters. Limited enrollment.
*3-4 units, Aut (Cutkosky, Leifer)*

**ME 310X. Tools for Team-Based Design Global Teaming Lab**—(Same as ENGR 310X.) Participation in a global design team with students in Sweden or Japan. Limited enrollment. Prerequisite: consent of instructor. Corequisite: ENGR 310A,B,C.
*1 unit, Aut, Win, Spr (Cutkosky, Leifer)*

**ME 310B,C. Design Project Experience with Corporate Partners**—(Same as ENGR 310B,C.) Two quarter project for graduate students with design experience who want involvement in an entrepreneurial design team with real world industrial partners. Products developed are part of the student's portfolio. Each team functions as a small startup company with a technical advisory board of the instructional staff and a coach. Computer-aided tools for project management, communication, and documentation; budget provided for direct expenses including technical assistants and conducting tests. Corporate liaisons via site visits, video conferencing, email, fax, and phone. Hardware demonstrations, peer reviews, scheduled documentation releases, and a team environment provide the mechanisms and culture for design information sharing. Enrollment by consent of instructor; depends on a pre-enrollment survey in December and recommendations by project definition teams in 310A. For some projects, 217 and 218 may be prerequisites or corequisites; see http://me310.stanford.edu for admission guidelines.
*3-4 units, Win, Spr (Cutkosky, Leifer)*

**ME 312. Advanced Product Design: Formgiving**—Small- and medium-scale design projects carried to a high degree of aesthetic refinement. Emphasis is on generating appropriate forms to the task and setting. Prerequisites: 115, ARTHIST 160.
*3-4 units, Win (Burnett)*

**ME 313. Human Values and Innovation in Design**—Introduction to the philosophy, spirit, and tradition of the product design program. Hands-on design projects used as vehicles for design thinking, visualization, and methodology. The relationships among technical, human, aesthetic, and business concerns. Drawing, prototyping, and design skills. Focus is on tenets of design philosophy: point of view, user-centered design, design methodology, and iterative design. Enrollment limited to 60.
*3 units, Aut (Kelley)*

**ME 314. Good Products, Bad Products**—(Formerly 214.) The characteristics of industrial products that cause them to be successes or failures: the straightforward (performance, economy, reliability), the complicated (human and cultural fit, compatibility with the environment, craftsmanship, positive emotional response of the user), the esoteric (elegance, sophistication, symbolism). Engineers and business people must better understand these factors to produce more successful products. Projects, papers, guest speakers, field trips. Limited enrollment. GER:2b
*3-4 units, Win (Beach)*

**ME 315. The Designer in Society**—(Formerly 215.) Open to all graduate students. Participants' career objectives and psychological orientation are compared with existing social values and conditions. Emphasis is on assisting individuals in assessing their roles in society. Readings on political, social, and humanistic thought are related to technology and design. Experiential, in-class exercises, and term project. Attendance mandatory. Enrollment limited to 24.
*3 units (Roth) not given 2004-05*

**ME 316A,B,C. Product Design Master's Project**—(Formerly 211A,B,C.) For Product Design or Design (Art) majors only. Students create and present two master's theses under the supervision of engineering and art faculty. Theses involve the synthesis of aesthetics and technological concerns in the service of human need and possibility. Product Design students take for 4 units; Art students for 2 units. Corequisite: ARTHIST 360.
*2-4 units, Aut, Win, Spr (Kelley)*

**ME 317A. Design for Manufacturability: Product Definition for Market Success**—(Formerly 217A.) Systematic methodologies to define, develop, and produce world-class products. Student teams work on projects to identify opportunities for improvement and develop a comprehensive product definition. Topics: value engineering, quality function deployment, design for assembly and producibility, design for variety and supply chain, design for life-cycle quality, and concurrent engineering. Students must take ME217B to complete the project and obtain a letter grade. On-campus class limited to 28. SCPD class does not have a limit, but each site must have at least 3 students to form a project team and define a project.
*4 units, Win (Ishii)*

**ME 317B. Design for Manufacturability: Quality by Design for Customer Value**—(Formerly 217B.) Building on 317A, focus is on the implementation of competitive product design. Student groups apply structured methods to optimize the design of an improved product, and plan for its manufacture, testing, and service. The project deliverable is a comprehensive product and process specification. Topics: concept generation and selection (Pugh's Method), FMEA applied to the manufacturing process, design for robustness, Taguchi Method, SPC and six sigma process, tolerance analysis, flexible manufacturing, product testing, rapid prototyping. Enrollment limited to 40, not including SITN students. Minimum enrollment of two per SITN viewing site; single student site by prior consent of instructor. On-campus class limited to 25. For SITN students, no enrollment limit, but each site must have a minimum of three students to form a project team and define a project on their own. Prerequisite: 317A.
*4 units, Spr (Ishii)*

**ME 317C. Manufacturing Systems Design**—(Enroll in MS&E 164/264.)
*3 units, Aut (Erhun)*

**ME 318. Computer-Aided Product Creation**—(Formerly 213.) Design course concentrating on an integrated suite of modern computer tools: rapid prototyping, solid modeling, computer-aided machining, computer numerical control manufacturing. Students choose, design, and manufacture individual products, emphasizing product definition, user benefits, and computer design tools. Manufacturing focuses on CNC machining. Stanford's Product Realization Lab's relationship to the outside world. Structured lab experiences build a basic CAD/CAM/CNC proficiency. Limited enrollment.
*4 units, Win (Milroy), Spr (Beach)*

**ME 320. Introduction to Robotics**—(Enroll in CS 223A.)
*3 units, Win (Khatib)*

**ME 321. Materials Selection In Design**—(Enroll in MATSCI 170/270.)
*3-4 units (Prinz) not given 2004-05*

**ME 322. Kinematic Synthesis of Mechanisms**—(Formerly 222.) The rational design of linkages. Techniques are presented to determine linkage proportions to fulfill various design requirements using analytical, graphical, and computer based methods.
*3 units, Win (Roth)*

**ME 323. Modeling and Identification of Mechanical Systems for Control**—The art and science behind developing mathematical models for control system design. Theoretical and practical system modeling and parameter identification. Frequency domain identification, parametric modeling, and black-box identification. Analytical work and laboratory experience with identification, controller implementation, and the implications of unmodeled dynamics and non-linearities. Prerequisites: linear algebra and system simulation with MATLAB/SIMULINK; ENGR 105.
*3 units, Aut (Gerdes)*

**ME 324. Precision Engineering**—(Formerly 224.) Advances in engineering are often enabled by more accurate control of manufacturing and measuring tolerances. Concepts and technology enable precision such that the ratio of overall dimensions to uncertainty of measurement is large relative to normal engineering practice. Typical application areas: non-spherical optics, computer information storage devices, and manufacturing metrology systems. Application experience is gained through the design and manufacture of a precision engineering project, emphasizing the principles of precision engineering. Lectures, structured labs, and field trips. Prerequisite: consent of instructors.
*4 units, Spr (Beach, DeBra)*

**ME 325. Interdisciplinary Interaction Design**—(Same as CS 447; formerly 293.) Small teams develop technology prototypes combining product and interaction design. Focus is on software and hardware interfaces, interaction, design aesthetics, and underpinnings of successful design including a reflective, interactive design process, group dynamics of interdisciplinary teamwork, and working with users. Prerequisite: CS 247A.
*3-4 units, Win (Kelley, Winograd)*

**ME 326. Telerobotics and Human-Robot Interactions**—Analysis of telerobotics and human-robot interactions with focus on dynamics and controls. Evaluation and implementation of required control systems. Topics include master-slave systems, kinematic and dynamic similarity; control architecture, force feedback, haptics, sensory substitutions; stability, passivity, sensor resolution, servo rates; time delays, prediction, wave variables. Hardware-based projects encouraged, which may complement ongoing research or inspire new developments. Prerequisites: ENGR 205, 320 or CS 223A, or consent of instructor. Limited enrollment.
*3 units, Win (Niemeyer) alternate years, not given 2005-06*

**ME 327A. Advanced Robotics**—(Enroll in CS 327A.)
*3 units, Spr (Khatib)*

**ME 329. Physical Solid Mechanics**—(Formerly 229.) Quantum mechanics, statistical mechanics, and solid state physics for engineering students. Theory describing physical processes at nanoscale in solid materials. Atomic structures of solids and their electronic structures. Statistical mechanics provides a theoretical framework for thermodynamics to connect the nanoscale processes to macroscopic properties of solids.
*3 units, Aut (Cho)*

**ME 330. Advanced Kinematics**—(Formerly 230.) Kinematics from mathematical viewpoints. Introduction to algebraic geometry of point, line, and plane elements. Emphasis is on basic theories which have potential application to mechanical linkages, computational geometry, and robotics.
*3 units (Roth) not given 2004-05*

**ME 331A. Classical Dynamics**—(Same as AA 242A.) Accelerating and rotating reference frames. Kinematics of rigid body motion; Euler angles, direction cosines. D'Alembert's principle, equations of motion. Inertia properties of rigid bodies. Dynamics of coupled rigid bodies. Lagrange's equations and their use. Dynamic behavior, stability, and small departures from equilibrium. Prerequiste: ENGR 15 or equivalent.
*3 units, Aut (Rock)*

**ME 331B. Advanced Dynamics**—(Same as AA 242B.) Formulation of equations of motion with Newton/Euler equations; angular momentum principle; D'Alembert principle; power, work, and energy; Kane's method; and Lagrange's equations. Numerical solutions of nonlinear algebraic and dfferential equations govering the behavior of multiple degree of freedom systems. Computer simulation of multi-body dynamic systems. Computer simulation of multi-body dynamic systems. Computed torque control.
*3 units, Win (Mitiguy)*

**ME 333. Mechanics**—Goal is a common basis for advanced mechanics courses. Formulation of the governing equations from physical and Lagrangian perspectives. Examples include systems of particles and linear elastic solids. Linear elasticity formulation in the static and dynamic cases, and elementary measures of stress and strain. Tensor and variational calculus.
*3 units, Aut (Lew)*

**ME 335A. Finite Element Analysis**—(Formerly 235A.) Emphasis is on fundamental concepts and techniques of primal finite element methods. Method of weighted residuals, Galerkin's method, and variational equations. Linear elliptic boundary value problems in one, two, and three space dimensions; applications in structural, solid, and fluid mechanics and heat transfer. Properties of standard element families and numerically integrated elements. Implementation of the finite element method. Active column equation solver, assembly of equations, and element routines. The mathematical theory of finite elements.
*3 units, Aut (Pinsky)*

**ME 335B. Finite Element Analysis**—(Formerly 235B.) Finite element methods for linear dynamic analysis. Eigenvalue, parabolic, and hyperbolic problems. Mathematical properties of semi-discrete (t-continuous) Galerkin approximations. Modal decomposition and direct spectral truncation techniques. Stability, consistency, convergence, and accuracy of ordinary differential equation solvers. Asymptotic stability, overshoot, and conservation laws for discrete algorithms. Mass reduction. Applications in heat conduction, structural vibrations, and elastic wave propagation. Computer implementation of finite element methods in linear dynamics. Implicit, explicit, and implicit-explicit algorithms and code architectures.
*3 units, Win (Pinsky)*

**ME 335C. Finite Element Analysis**—(Formerly 235C.) Nonlinear continuum mechanics. Galerkin formulation of nonlinear elliptic, parabolic, and hyperbolic problems. Explicit, implicit, and implicit-explicit algorithm in nonlinear transient analysis. Stability of ordinary differential equation solvers for nonlinear problem classes; energy-conserving algorithms. Automatic time-step selection strategies. Methods of solving nonlinear algebraic systems. Newton-type methods and quasi-Newton updates. Iterative procedures. Arc-length methods. Architecture of computer codes for nonlinear finite element analysis. Applications from structural and solid mechanics, e.g., nonlinear elasticity.
*3 units, Spr (Pinsky)*

**ME 337. Free and Forced Motion of Structures**—(Enroll in AA 244A.)
*3 units (Staff) not given 2004-05*

**ME 338A. Continuum Mechanics**—(Formerly 238A.) Review of tensor algebra and calculus. Kinematics of continuum deformation; finite deformations and compatibility; measures of strain and stress; linearized kinematics; conservation laws for mass, momenta, and energy; Lagrangian formulation of continuum mechanics; symmetries and Noether's theorem; continuum thermodynamics.
*3 units, Win (Lew)*

**ME 338B. Continuum Mechanics**—Constitutive theory; equilibrium constitutive relations; material frame indifference and material symmetry; finite elasticity; formulation of the boundary value problem; linearization and well-posedness; symmetries and configurational forces; numerical considerations. GER:2b
*3 units (Lew) not given 2004-05*

**ME 339. Mechanics of the Cell**—Kinematical description of basic structural elements used to model parts of the cell: rods, ropes, membranes, and shells. Formulation of constitutive equations: nonlinear elasticity and entropic contributions. Elasticity of polymeric networks. Applications to model basic filaments of the cytoskeleton: actin, microtubules, intermediate filaments, and complete networks. Applications to biological membranes.
*3 units, Spr (Lew)*

**ME 340A. Theory and Applications of Elasticity**—(Formerly 240A.) Concepts of deformation, strain, stress, and strain energy. Kinematic relations, generalized Hooke's law, and symmetry properties of elastic constants. Compatibility and uniqueness of solutions. Formulation of plane boundary value problems and solution methods using stress functions. Elastic waves in deformable solids. Stress concentration at holes, inclusions, dislocations, and cracks. Prerequisite: 338A or equivalent, or consent of instructor.
*3 units (Barnett) not given 2004-05*

**ME 340B. Elasticity in Microscopic Structures**—Elasticity theory and applications to structures in micro devices, material defects, and biological systems. Theoretical basis: stress, strain, and energy; equilibrium and compatibility conditions; boundary value problem formulation. Solution methods: stress function, Green's function, and Fourier transformation; moderate numerical exercises using Matlab. Methods and solutions applied to the elastic behaviors of thin films and MEMS structures, cracks and dislocations, and cell filaments and membranes.
*3 units, Win (Cai)*

**ME 341. Building Mathematical Models in Biomechanics**—Theory and practice of mathematical models. Based on the research literature, examples from hearing and speech sciences, orthopedic bioengineering, and neuromuscular biomechanics. General, meta-theoretical issues that go beyond the particular subject matter. Examples include: What is a model? What constitutes a good model? What is the process of building a model? What are the different approaches to modeling? Dualisms in modeling include: the interplay between theory and experiment, analytic and computational models, and forward and inverse approaches.
*3 units (Puria) not given 2004-05*

**ME 342A. MEMS Laboratory**—Practice and theory of MEMS device design and fabrication, orientation to fabrication facilities, and introduction to techniques for design and evaluation of MEMS devices in the context of designed projects. Emphasis on MEMS design (need finding, brainstorming, evaluation, and design methodology), characterization, and fabrication, including photolithography, etching, oxidation, diffusion, and ion implanation. Limited enrollment. Prerequisite: engineering or science background and consent of instructor.
*4 units, Spr (Pruitt)*

**ME 342B. MEMS Laboratory II**—Emphasis is on team-based innovative design, prototyping, and characterization of new devices driven by customer requirements and the study of the device and market. Limited enrollment. Rerequisite: 342A.
*4 units, Sum (Pruitt)*

**ME 342D. MEMS Laboratory Assignments**—Prerequisite: consent of instructor.
*1-2 units, Spr (Pruitt)*

**ME 343. An Introduction to Waves in Elastic Solids**—One-dimensional motion of an elastic continuum, the linearized theory of elasticity and elastodynamic theory, elastic waves in an unbounded medium, plane harmonic waves in elastic half-spaces including reflection and refraction, slowness, energy velocity and anisotropic effects. Text is first five chapters of Achenbach's *Wave Propagation in Elastic Solids*.
*3 units, Spr (Barnett)*

**ME 344A. Computational Nanotechnology**—(Formerly 244A.) Atomistic simulations as computational tools to design nanoscale materials and devices. Nanoparticles and nanowires introduced as main classes of nano building blocks. Computational modeling of carbon nanomaterials (fullerenes and nanotubes); nanoparticles and quantum dots; semiconductor and metal nanowires; and molecular wires. Atomistic modeling programs with graphical user interface used to gain hands-on experience of nanomaterials design. GER:2b
*3 units, Win (Cho)*

**ME 344B. Nanomaterials Modeling**—(Formerly 244B.) Atomistic and quantum mechanical simulation methods. Focus is quantum simulation of nanomaterials. Review of concepts and practical techniques of atomistic simulations; finite difference algorithms and practical computational issues for molecular dynamics and Monte Carlo simulations. Graphical user interface, designing nanomaterials through analysis and feedback processes, configuration optimization, dynamic mode analysis, and electronic structure analysis. Hands-on experience in computational design of nanomaterials, and fundamentals of simulations.
*3 units, Spr (Cho)*

**ME 345. Fatigue Design and Analysis**—(Formerly 245.) The mechanism and occurrences of fatigue in service. Methods for predicting fatigue life and for protecting against premature fatigue failure. Use of elastic stress and inelastic strain analyses to predict crack initiation life. Use of linear elastic fracture mechanics to predict crack propagation life. Effects of stress concentrations, manufacturing processes, load sequence, irregular loading, multi-axial loading. Subject is treated from the viewpoints of the engineer seeking up-to-date methods of life prediction and the researcher interested in improving understanding of fatigue behavior. Prerequisite: undergraduate mechanics of materials.
*3 units, Win (Nelson)*

**ME 346. Introduction to Molecular Simulations**—Basic steps of molecular simulations: model set-up, algorithm iteration, data analysis, and visualization. Molecular dynamics, Monte Carlo, and energy minimization algorithms. Elementary statistical mechanics (ensemble, phase transition, and free energy). Advanced simulation techniques introduced through example: mechanical properties of solids (atomic measure of stress and strain, modes of deformation and failure, defect energy, and kinetics); liquids (linear response theory, correlation functions, and transport coefficients); structure of bio-molecules (protein folds, and energy versus entropy competition).
*3 units, Aut (Cai)*

**ME 348. Experimental Stress Analysis**—(Formerly 248.) Theory and applications of photoelasticity, strain gages, and holographic interferometry. Comparison of test results with theoretical predictions of stress and strain. Other methods of stress and strain determination (optical fiber strain sensors, thermoelasticity, Moire, residual stress determination).
*3 units, Spr (Nelson)*

**ME 351A. Fluid Mechanics**—(Formerly 251A.) Exact and approximate analysis of fluid flow covering kinematics, global and differential equations of mass, momentum, and energy conservation. Forces and stresses in fluids. Euler's equations and the Bernoulli theorem applied to inviscid flows. Vorticity dynamics. Topics in irrotational flow: stream function and velocity potential for exact and approximate solutions; superposition of solutions; complex potential function; circulation and lift. Some boundary layer concepts.
*3 units, Aut (Lele)*

**ME 351B. Fluid Mechanics**—(Formerly 251B.) Laminar viscous fluid flow. Governing equations, boundary conditions, and constitutive laws. Exact solutions for parallel flows. Creeping flow limit, lubrication theory, and boundary layer theory including free-shear layers and approximate methods of solution; boundary layer separation. Introduction to stability theory and transition to turbulence, and turbulent boundary layers. Prerequisite: 351A.
*3 units, Win (Staff)*

**ME 352A. Radiative Heat Transfer**—(Formerly 252A.) The fundamentals of thermal radiation heat transfer; blackbody radiation laws; radiative properties of non-black surfaces; analysis of radiative exchange between surfaces and in enclosures; combined radiation, conduction, and convection; radiative transfer in absorbing, emitting, and scattering media. Advanced material for students with interests in heat transfer, as applied in high-temperature energy conversion systems. Take 352B,C for depth in heat transfer. Prerequisites: graduate standing and undergraduate course in heat transfer. Recommended: computer skills.
*3 units, Aut (Mitchell) alternate years, not given 2005-06*

**ME 352B. Fundamentals of Heat Conduction**—(Formerly 252B.) Physical description of heat conduction in solids, liquids, and gases. The heat diffusion equation and its solution using analytical and numerical techniques. Data and microscopic models for the thermal conductivity of solids, liquids, and gases, and for the thermal resistance at solid-solid and solid-liquid boundaries. Introduction to the kinetic theory of heat transport, focusing on applications for composite materials, semiconductor devices, micromachined sensors and actuators, and rarefied gases. Prerequisite: consent of instructor.
*3 units, Win (Goodson)*

**ME 352C. Convective Heat Transfer**—(Formerly 252C.) Prediction of heat and mass transfer rates based on analytical and numerical solutions of the governing partial differential equations. Heat transfer in fully developed pipe and channel flow, pipe entrance flow, laminar boundary layers, and turbulent boundary layers. Superposition methods for handling non-uniform wall boundary conditions. Approximate models for turbulent flows. Comparison of exact and approximate analyses to modern experimental results. General introduction to heat transfer in complex flows. Prerequisite: 351B or equivalent.
*3 units, Spr (Eaton)*

**ME 354. Experimental Methods in Fluid Mechanics**—Experimental methods associated with the interfacing of laboratory instruments, experimental control, sampling strategies, data analysis, and introductory image processing. Instrumentation including point-wise anemometers and particle image tracking systems. Lab. Prerequisites: previous experience with computer programming and consent of instructor. Limited enrollment.
*4 units, Aut (Santiago)*

**ME 355. Compressible Flow**—(Formerly 255.) Recommended for students with little experience in compressible flow. Introduction to compressible flow. Sound waves and normal shock waves. Quasi-one-dimensional steady flows in variable area ducts with friction, heating, and cooling; unsteady one-dimensional flow, two-dimensional supersonic flow; oblique shock waves, Prandtl-Meyer expansions, detonation waves, method of characteristics.
*3 units (Mungal) not given 2004-05*

**ME 358. Heat Transfer in Microdevices**—(Formerly 258.) Application-driven introduction to the thermal design of electronic circuits, sensors, and actuators that have dimensions comparable to or smaller than one micrometer. The impact of thin-layer boundaries on thermal conduction and radiation. Convection in microchannels and microscopic heat pipes. Thermal property measurements for microdevices. Emphasis is on Si and GaAs semiconductor devices and layers of unusual, technically-promising materials such as chemical-vapor-deposited (CVD) diamond. Final project based on student research interests. Prerequisite: consent of instructor.
*3 units, Spr (Goodson)*

**ME 359A. Advanced Design and Engineering of Space Systems I**—The application of advanced theory and concepts to the development of spacecraft and missile subsystems; taught by experts in their fields. Practical aspects of design and integration. Mission analysis, systems design and verification, radiation and space environments, orbital mechanics, space propulsion, electrical power and avionics subsystems, payload communications, and attitude control. Subsystem-oriented design problems focused around a mission to be completed in groups. Tours of Lockheed Martin facilities. Limited enrollment. Prerequisites: undergraduate degree in related engineering field or consent of instructor.
*4 units, Win (Khayms)*

**ME 359B. Advanced Design and Engineering of Space Systems II**—Continuation of 359A. Topics include aerospace materials, mechanical environments, structural analysis and design, finite element analysis, mechanisms, thermal control, probability and statistics. Tours of Lockheed Martin facilities. Limited enrollment. Prerequisites: undergraduate degree in related field, or consent of instructor.
*4 units, Spr (Yiu)*

**ME 361. Turbulence**—Governing equations. Averaging and correlations. Reynolds equations and Reynolds stresses. Free shear flows, turbulent jet, turbulent length and time scales, turbulent kinetic energy and kinetic energy dissipation, and kinetic energy budget. Kolmogorov's hypothesis and energy spectrum. Wall bounded flows, channel flow and boundary layer, viscous scales, and law of the wall. Turbulence modeling, gradient transport and eddy viscosity, mixing length model, two-equation models, Reynolds-stress model, and large-eddy simulation.
*3 units, Spr (Pitsch)*

**ME 362A. Physical Gas Dynamics**—(Formerly 262A.) Concepts and techniques for description of high-temperature and chemically reacting gases from a molecular point of view. Introductory kinetic theory, chemical thermodynamics, and statistical mechanics as applied to properties of gases and gas mixtures. Transport and thermodynamic properties, law of mass action, and equilibrium chemical composition. Maxwellian and Boltzmann distributions of velocity and molecular energy. Examples and applications from areas of current interest, e.g., combustion and materials processing.
*3 units, Aut (Cappelli)*

**ME 362B. Nonequilibrium Processes in High-Temperature Gases**—(Formerly 262B.) Introduction to chemical kinetics and energy transfer in high-temperature gases. Collision theory, transition state theory, and unimolecular reaction theory. Prerequisie: 362A or consent of instructor.
*3 units, Win (Hanson)*

**ME 363. Partially Ionized Plasmas and Gas Discharges**—(Formerly 263.) Introduction to partially ionized gases and the nature of gas discharges. Topics: the fundamentals of plasma physics emphasizing collisional and radiative processes, electron and ion transport, ohmic dissipation, oscillations and waves, interaction of electromagnetic waves with plasmas. Applications: plasma diagnostics, plasma propulsion and materials processing. Prerequisite: 362A or consent of instructor.
*3 units, Win (Cappelli)*

**ME 364. Optical Diagnostics and Spectroscopy**—(Formerly 264.) Introduction to the spectroscopy of gases and laser-based diagnostic techniques for measurements of species concentrations, temperature, density, and other flow field properties. Topics: electronic, vibrational, and rotational transitions; spectral lineshapes and broadening mechanisms; absorption, fluorescence, Rayleigh and Raman scattering methods; collisional quenching. Prerequisite: 362A or equivalent.
*3 units (Hanson) not given 2004-05*

**ME 367. Optical Diagnostics and Spectroscopy Laboratory**—(Formerly 267.) Introduction to the principles, procedures, and instrumentation associated with optical measurements in gases and plasmas. Absorption, fluorescence and emission, and light-scattering methods. Measurements of temperature, species concentration, and molecular properties. Lab. Enrollment limited to 16. Prerequisites: 362A and/or 364.
*4 units, Spr (Hanson)*

**ME 370A. Energy Systems I: Thermodynamics**—Thermodynamic analysis of energy systems emphasizing systematic methodology for and application of basic principles to generate quantitative understanding. Availability, mixtures, reacting systems, phase equilibrium, chemical availability, and modern computational methods for analysis. Prerequisite: undergraduate background in engineering thermodynamics and computer skills such as Matlab.
*3 units, Aut (Bowman)*

**ME 370B. Energy Systems II: Modeling and Advanced Concepts**—Development of quantitative device models for complex energy systems, including fuel cells, reformers, combustion engines, and electrolyzers, using thermodynamic and transport analysis. Student groups work on energy systems to develop conceptual understanding, and high-level, quantitative and refined models. Advanced topics in thermodynamics and special topics associated with devices under study. Prerequisite: 370A.
*4 units, Win (Edwards)*

**ME 370C. Energy Systems III: Projects**—Refinement and calibration of energy system models generated in ME 370B carrying the models to maturity and completion. Integration of device models into a larger model of energy systems. Prerequisites: 370A, 370B, consent of instructor.
*3-5 units, Spr (Edwards)*

**ME 371. Combustion Fundamentals**—(Formerly 271.) Heat of reaction, adiabatic flame temperature, and chemical composition of products of combustion; kinetics of combustion and pollutant formation reactions; conservation equations for multi-component reacting flows; propagation of laminar premixed flames and detonations. Prerequisite: 362A or 370; or consent of instructor.
*3 units, Win (Mitchell)*

**ME 372. Combustion Applications**—(Formerly 272.) The role of chemical and physical processes in combustion; ignition, flammability, and quenching of combustible gas mixtures; premixed turbulent flames; laminar and turbulent diffusion flames; combustion of fuel droplets and sprays. Prerequisite: 371.
*3 units, Spr (Bowman)*

**ME 374A,B. Biodesign Innovation**—(Same as BIOE 374A,B; MED 272A,B.)

**ME 374A. Needs Finding and Concept Creation**—Two quarter sequence. Strategies for understanding and interpreting clinical needs, researching literature, and searching patents. Clinical and scientific literature review, techniques of intellectual property analysis and feasibility, basic prototyping, and market assessment. Students working in small entrepreneurial teams to create, analyze, and screen medical technology ideas, and select projects for future development.
*3-4 units, Win (Makower, Yock, Zenios)*

**ME 374B: Concept Development and Implementation**—Two quarter sequence. Early factors for success; how to prototype inventions and refine intellectual property. Lectures guest medical pioneers and entrepreneurs about strategic planning, ethical considerations, new venture management, and financing and licensing strategies. Cash requirements; regulatory (FDA), reimbursement, clinical, and legal strategies, and business or research plans.
*3-4 units, Spr (Makower, Yock, Zenios)*

**ME 381. Orthopaedic Bioengineering**—(Same as BIOE 381.) Engineering approaches are applied to the musculoskeletal system in the context of surgical and medical care. Fundamental anatomy and physiology. Material and structural characteristics of hard and soft connective tissues and organ systems are considered and the role of mechanics in normal development and pathogenesis is addressed. Engineering methods used in the evaluation and planning of orthopaedic procedures, surgery, and devices.
*3 units, Aut (Carter)*

**ME 382A. Biomedical Device Design and Evaluation I**—(Formerly 282A.) Real world problems and challenges of biomedical device design and evaluation. Students engage in industry sponsored projects resulting in new designs, physical prototypes, design analyses, computational models, and experimental tests, gaining experience in: the formation of design teams; interdisciplinary communication skills; regulatory issues; biological, anatomical, and physiological considerations; testing standards for medical devices; and intellectual property.
*4 units, Win (Andriacchi)*

**ME 382B. Biomedical Device Design and Evaluation II**—(Formerly 282B.) Continuation of industry sponsored projects from 382A. With the assistance of faculty and expert consultants, students finalize product designs or complete detailed design evaluations of new medical products. Bioethics issues and strtegies for funding new medical ventures.
*4 units, Spr (Andriacchi)*

**ME 385A. Tissue Engineering**—(Same as BIOE 360A; formerly 285.) Tissue engineering is an expanding discipline that applies biological and engineering principles to create substitutes or replacements for defective tissues or organs. The principles of cell biology as a foundation for using engineering approaches to generate tissue structure and function. Emphasis is on how scaffolds, smart polymers, and mechanical forces can be used to reproduce the physical environment that acts, at the whole organ system level, to maintain specialized cellular function through molecular and genetic mechanisms.
*2 units, Win (Smith, Carter)*

**ME 385B. Tissue Engineering Lab**—(Same as BIOE 360B; formerly 285B.) Hands-on experience in the fabrication of living engineered tissues. Techniques to be covered include sterile technique, culture of mammalian cells, creation of cell-seeded scaffolds, and the effects of mechanical loading on the metabolism of living engineered tissues. The underlying theory and background for each technique are described followed by a practical demonstration. Students are then given access to the lab and provided with supplies and expected to develop hands-on proficiency.
*1 unit, Win (Jacobs)*

**ME 386. Neuromuscular Biomechanics**—(Same as BIOE 286; formerly 286.) The interplay between mechanics and neural control of movement. State of the art assessment through a review of classic and recent journal articles. Emphasis is on the application of dynamics and control to the design of assistive technology for persons with movement disorders.
*3 units (Delp) not given 2004-05*

**ME 389. Bioengineering and Biodesign Forum**—(Same as BIOE 389.) Invited speakers present research topics at the interfaces of biology, medicine, physics, and engineering.
*1 unit, Aut, Win, Spr (Staff)*

**ME 390. Thermosciences Research Project Seminar**—(Formerly 290.) Review of work in a particular research program and presentations of other related work. (AU)
*1 unit, Aut, Win, Spr (Staff)*

**ME 391. Engineering Problems**—(Formerly 291.) Directed study for graduate engineering students on subjects of mutual interest to student and staff member. May be used to prepare for experimental research during a later quarter under 392. Students must find a faculty sponsor.
*1-5 units, Aut, Win, Spr, Sum (Staff)*

**ME 392. Experimental Investigation of Engineering Problems**—(Formerly 292.) Graduate engineering students undertake experimental investigation under guidance of staff member. Previous work under 391 may be required to provide background for experimental program. Faculty sponsor required.
*1-5 units, Aut, Win, Spr, Sum (Staff)*

**ME 393. Biomimetic Locomotion Seminar**—(Formerly 294X.) Results from the study of animal locomotion and physiology and their implications for the design and control of small robots. Arthropods provide insights for building small robots that are robust and comparatively easy to control. Weekly forum. One or two papers are reviewed each week. Each student leads the discussion of one of the papers, with the guidance of the instructor.
*1 unit, Aut, Win, Spr (Cutkosky, Waldron)*

**ME 394. Design Forum**—(Formerly 294.) Introduction to the design faculty and research labs. Faculty describe their work and research interests followed by open discussion.
*1 unit, Aut (Niemeyer)*

**ME 395. Seminar in Solid Mechanics**—Problems in all branches of solid mechanics. All Ph.D. candidates in solid mechanics are normally expected to attend. (AU)
*1 unit, Aut, Win, Spr (Staff)*

**ME 396. Design and Manufacturing Forum**—(Formerly 296.) Invited speakers address issues of interest to design and manufacturing engineers. Presentations followed by discussion. Sponsored by Stanford Engineering Club for Automation and Manufacturing (SECAM). (AU)
*1 unit, Win, Spr (Staff)*

**ME 397. Design Theory and Methodology Forum**—(Formerly 297.) Research reports, literature reviews, and designer interviews promote rigorous examinations of the cognitive basis for designer behavior and design tool development. (AU)
*1-3 units, Aut, Win, Spr (Leifer, Mabogunje, Eris)*

## ADVANCED GRADUATE

**ME 400. Thesis (Engineer Degree)**—(Formerly 300.) Investigation of some engineering problems. Required of Engineer degree candidates.
*2-15 units, Aut, Win, Spr, Sum (Staff)*

**ME 405. Asymptotic Methods and Applications**—(Formerly 305.) Asymptotic versus convergent expansions, approximation of integrals, method of matched asymptotics, WKB method and turning points, method of multiple scales. Applications: viscous and potential flow, wave propagation, combustion, and electrostatics. Prerequistes: CME 204 (formerly ME 300B), graduate level fluid mechanics.
*3 units, Aut (Staff)*

**ME 406. Turbulence Physics and Modeling Using Numerical Simulation Data**
*2 units, Sum (Staff)*

**ME 408. Spectral Methods in Computational Physics**—(Enroll in CME 322.)
*3 units (Moin) not given 2004-05*

**ME 410. Multigrid Methods and Parallel Computation**—Multigrid methods to solve partial differential equations for engineering problems. Iterative methods: Jacobi, Guass-Seidel. Multigrid cycles, full multigrid. Multigrid theory, local Fourier analysis. Advanced multigrid, anistropic equations, nonlinear problems. Parallel multigrid, grid partitioning, parallel line smoothers. Algebraic multigrid. Application examples from aerodynamics, atmospheric and oceanic research, structural mechanics, and quantum mechanics. Prerequisites: advanced engineering mathematics, matrix theory (CME 200, formerly ME 300A), partial differential equations (CME 204, formerly ME 300B), and computer programming (C, C++, computational package such as MATLAB).
*3 units, Aut (Darve)*

**ME 414. Solid State Physics Issues for Mechanical Engineering Experiments**—(Formerly 314.) Introductory overview of the principles of statistical mechanics, quantum mechanics, and solid-state physics. Provides graduate mechanical engineering students with understanding needed to work on devices or technologies which rely on solid-state physics.
*3 units, Sum (Kenny)*

**ME 417. Total Product Integration Engineering**—(Formerly 317.) For students aspiring to be product development executives and leaders in dfM research and education. Advanced methods and tools beyond the material covered in 217: quality design across global supply chain, robust product architecture for market variety and technology advances, product development risk management. Small teams or individuals conduct a practical project that produces either an in-depth case study or a significant enhancement to the dfM methods and tools. Enrollment limited to 16. Prerequisites: 317AB.
*4 units, Aut (Ishii)*

**ME 420. Applied Electrochemistry: Micro- and Nanoscale**—Concepts of physical chemistry such as thermodynamic equilibrium, reaction kinetics, and mass transport mechanisms from which the fundamentals of electrochemistry are derived. Theory of electrochemical methods for material analyses and modifications with emphasis on scaling behaviors. Electrochemical devices such as sensors, actuators, and probes for scanning microscopes, and their miniaturization concepts. Examples of these devices built, characterized, and applied in labs using technologies such as scanning probe techniques. Projects focus on current problems in biology, material science, microfabrication, and energy conversion.
*3 units, Aut (Fasching)*

**ME 444A. Quantum Simulations of Molecules and Materials**—(Enroll in CHEMENG 444A.)
*3 units (Staff) not given 2004-05*

**ME 444B. Quantum Simulations: Materials Micro Mechanics**—(Formerly 249B.) Quantum atomistic simulations of materials to predict structure, strength, defect energetics and motion, and surfaces and

interfaces. Tight-binding and density functional methods for covalent, ionic, and metallic solids. Pseudopotential and plane wave basis for ab initio solid electronic structure calculations. Applications to real materials systems including micromechanics of electronic devices, MEMS, nanotechnology, and biomaterials.
*3 units (Staff) not given 2004-05*

**ME 451A. Advanced Fluid Mechanics**—(Formerly 351A.) For advanced students specializing in fluid mechanics. Topics: kinematics (analysis of deformation, critical points and flow topology, Helmholtz decomposition); constitutive relations (viscous and visco-elastic flows, non-inertial frames); vortex dynamics; circulation theorems, vortex line stretching and rotation, vorticity generation mechanisms, vortex filaments and Biot-Savart formula, local induction approximation, impulse and kinetic energy of vortex systems, vorticity in rotating frame. Prerequisite: graduate level courses in compressible and viscous flow.
*3 units (Staff) not given 2004-05*

**ME 451B. Advanced Fluid Mechanics**—(Formerly 351B.) Waves in fluids: surface waves, internal waves, inertial and acoustic waves, dispersion and group velocity, wave trains, transport due to waves, propagation in slowly varying medium, wave steepening, solitons and solitary waves, shock waves. Stability of fluid motion: dynamical systems, bifurcations, Kelvin-Helmholtz instability, Rayleigh-Benard convection, energy method, global stability, linear stability of parallel flows, necessary and sufficient conditions for stability, viscosity as a destabilizing factor. Focus is on flow instabilities. Prerequisites: graduate-level courses in compressible and viscous flow.
*3 units (Lele) alternate years, given 2005-06*

**ME 451C. Advanced Fluid Mechanics**—(Formerly 351C). Compressible flow: governing equations, Crocco-Vazsonyi's equations, creation and destruction of vorticity by compressibility effects, shock waves. Modal decomposition of compressible flow, linear and nonlinear modal interactions, interaction of turbulence with shock waves. Energetics of compressible turbulence, effects of compressibility on free-shear flows, turbulent boundary layers, Van Direst transformation, recovery temperature, and shock/boundary layer interaction. Strong Reynolds analogy, modeling compressible turbulent flows. Prerequisites: 355, 361A, or equivalent.
*3 units, Win (Staff)*

**ME 457. Fluid Flow in Microdevices**—(Formerly 257.) Introduction to the effects of physico-chemical forces on fluid flow of micron-scales. Creeping flow, charge double-layers, and electrochemical transport (e.g., Nernst-Planck equations); the hydrodynamics of solutions of charged and uncharged particles. Device applications of interest include microsystems that perform capillary electrophoresis, drug dispension, and hybridization assays. Emphasis is on bioanalytical applications where electrophoresis, electro-osmosis, and Brownian motion effects are important. Prerequisite: consent of instructor.
*3 units (Santiago) not given 2004-05*

**ME 459. Frontiers in Interdisciplinary Biosciences**—(Crosslisted in departments in the schools of H&S, Engineering, and Medicine; student register through their affiliated departments; otherwise register for CHEMENG 459) See CHEMENG 459 or http://biox.stanford.edu/courses/459_announce.html
*1 unit, Aut, Win, Spr (Robertson)*

**ME 461. Advanced Topics in Turbulence**—(Formerly 261B.) Topics vary each year and may include: spectral representation, rapid distortion theory, Cayley-Hamilton theorem and constitutive modeling of turbulence, turbulent dispersion, stochastic differential equations, Reynolds average and modeling for reacting flows, vortical structures (topology), intermittancy, proper orthogonal characteristic eddy decomposition, chaos, Lyapunoff exponents, fractals, large eddy simulations, subgrid closure, and geophysical turbulence.
*3 units, Win (Staff)*

**ME 469A. Computational Methods in Fluid Mechanics**—(Formerly 269A.) Advanced methods for solving systems of linear equations: multigrid and conjugate gradient methods; methods for potential flow; integral methods for boundary layers and their coupling to potential flow solutions; methods for the boundary layer equations; methods for solving the incompressible flow equations on structured grids: projection, fractional step and artificial compressibility methods. Students use and modify provided codes. Prerequisites: CME 206 (formerly ME 300C), 351B, or equivalents.
*3 units, Win (Farhat)*

**ME 469B. Computational Methods in Fluid Mechanics**—(Formerly 269B.) Introduction to advanced CFD codes. Geometry modeling, CAD-CFD conversion. Structured and unstructured mesh generation. Solution methods for steady and unsteady incompressible Navier-Stokes equations. Turbulence modeling. Conjugate (solid/fluid) heat transfer problems. Development of customized physical models. Batch execution for parametric studies. Final project involving solution of a problem of student's choosing. Prerequiste: CME 206 (formerly ME 300C).
*3 units, Spr (Iaccarino)*

**ME 471. Turbulent Combustion**—Basis of turbulent combustion models. Assumption of scale separation between turbulence and combustion, resulting in Reynolds number independence of combustion models. Level-set approach for premixed combustion. Different regimes of premixed turbulent combustion with either kinematic or diffusive flow/chemistry interaction leading to different scaling laws and unified expression for turbulent velocity in both regimes. Models for non-premixed turbulent combustion based on mixture fraction concept. Analytical predictions for flame length of turbulent jets and NOx formation. Partially premixed combustion. Analytical scaling for lift-off heights of lifted diffusion.
*3 units (Pitsch) not given 2004-05*

**ME 484. Computational Methods in Cardiovascular Bioengineering**—(Formerly 184B.) Lumped parameter, one-dimensional nonlinear and linear wave propagation, and three-dimensional modeling techniques applied to simulate blood flow in the cardiovascular system system and evaluate the performance of cardiovascular devices. Construction of anatomic models and extraction of physiologic quantities from medical imaging data. Problems in blood flow within the context of disease research, device design, and surgical planning.
*3 units, Spr (Taylor)*

**ME 485. Modeling and Simulation of Human Movement**—(Same as BIOE 485; formerly 382.) Direct experience with the computational tools used to create simulations of human movement. Lecture/labs on animation of movement; kinematic models of joints; forward dynamic simulation; computational models of muscles, tendons, and ligaments; creation of models from medical images; control of dynamic simulations; collision detection and contact models. Prerequisite: 281, 331A,B, or equivalent.
*3 units, Spr (Delp)*

## Ph.D THESIS

**ME 500. Thesis (Ph.D.)**—(Formerly 301.)
*2-15 units, Aut, Win, Spr, Sum (Staff)*

## OVERSEAS STUDIES

Courses approved for the Mechanical Engineering major and taught overseas can be found in the "Overseas Studies" section of this bulletin, or in the Overseas Studies office, 126 Sweet Hall.

### FLORENCE

**ME 122F. The Art of Engineering and the Engineering of Art in Early Renaissance Italy**—GER:2b
*3 units, Spr (Cutkosky)*

**ME 123F. Design for Wellbeing in 21st-Century Tuscany**
*3 units, Spr (Cutkosky)*

# SCIENTIFIC COMPUTING AND COMPUTATIONAL MATHEMATICS PROGRAM

*Director:* Walter Murray

*Faculty:* Juan Alonso (Aeronautics and Astronautics), Kyeongjae Cho (Mechanical Engineering), Eric Darve (Mechanical Engineering), Robert Dutton (Electrical Engineering), Ronald Fedkiw (Computer Science), Margot Gerritsen (Petroleum Engineering), Peter Glynn (Management Science and Engineering), Gene Golub (Computer Science), Joseph B. Keller (Mathematics, emeritus), Sanjiva K. Lele (Aeronautics and Astronautics), Doron Levy (Mathematics), Walter Murray (Management Science and Engineering), Joseph Oliger (Computer Science, emeritus); Peter M. Pinsky (Mechanical Engineering), Michael A. Saunders (Management Science and Engineering)

*Affiliated Faculty:* Khalid Aziz (Petroleum Engineering), S. Boyd (Electrical Engineering), J. Cioffi (Electrical Engineering), R. Cottle (Management Science and Engineering), T. Cover (Electrical Engineering), G. Dantzig (Management Science and Engineering, emeritus), A. Dembo (Mathematics, Statistics), S. Doniach (Applied Physics, Physics), D. Donoho (Statistics), C. Eaves (Management Science and Engineering, emeritus), Joel Ferziger (Mechanical Engineering), J. Friedman (Statistics), I. Johnstone (Statistics, Health Research and Policy), Thomas Kailath (Electrical Engineering, emeritus), J. Koseff (Civil and Environmental Engineering), K. Law (Civil and Environmental Engineering), T. P. Liu (Mathematics), R. MacCormack (Aeronautics and Astronautics), P. Moin (Mechanical Engineering), A. B. Owen (Statistics), W. Reynolds (Mechanical Engineering, emeritus), B. Roth (Mechanical Engineering), Eric Shaqfeh (Chemical Engineering, Mechanical Engineering), C. Steele (Mechanical Engineering, Aeronautics and Astronautics), R. Street (Civil and Environmental Engineering, Mechanical Engineering)

*Web Site:* http://www-sccm.stanford.edu

Courses given in Scientific Computing and Computational Mathematics have the subject code SCCM. For a complete list of subject codes, see Appendix.

The Scientific Computing and Computational Mathematics Program (SC/CM) is interdisciplinary and leads to the M.S. and Ph.D. degrees. It is designed for students interested in studying and developing computational tools in those aspects of applied mathematics central to modeling in the physical and engineering sciences. Graduates of this program are expected to be able to deal with a scientific problem from its formulation, moving through its mathematical analysis to algorithm development and implementation. The symbiosis of applied mathematics and numerical computing is stressed.

The SC/CM program is an integral part of the new Institute of Computational and Mathematics Engineering (ICME); all SC/CM students are members of ICME. For further information on ICME, see the "Institute for Computational and Mathematical Engineering" section of this bulletin.

## GRADUATE PROGRAMS

## MASTER OF SCIENCE

The University's basic requirements for the M.S. degree are discussed in the "Graduate Degrees" section of this bulletin.

A candidate must complete a program of 45 units of courses numbered 100 or greater. In addition, a number of courses at the 200 level or above are required. At least 36 of these units must be graded units, passed with a grade point average (GPA) of 3.0 (B) or better. The core curriculum is common to all degrees offered by the program, but is adapted according to the interests and prior education of the student. Deviations from the core curriculum must be justified in writing and approved by the student's adviser and the SC/CM Committee. Courses that are waived rather than taken may not be counted towards the master's degree. The student must fulfill credit requirements in each of the categories listed below.

### CORE CURRICULUM

1. *Mathematics* (12 units): students are required to take MATH 220A,B for a letter grade. Nine additional units in math are required with at least 6 units at the 200 level. Suggested courses are MATH 173, 205A,B,C, 220C, 222A, 226, 230, 236, 237, 256A,B,C, 274, 276A,B; STATS 300A,B,C, 305, 306A,B, 310A,B,C. Other courses from Statistics can be substituted with consent of the adviser and the SC/CM Committee. Students should take those courses most suitable to their areas of specialization.

2. *Numerical Analysis* (12 units): students are required to take CS 237A,B,C and an advanced course in numerical analysis such as: CS 335, 336, 337; MS&E 312; ME 233B, 235A,B,C; STATS 327. All 12 units must be for a letter grade.
3. *Optimization* (3 units): students are required to take MS&E 315.
4. *Computer Science* (5 units): students can select their courses, but must get approval for their selection from their adviser.
5. *Application Area* (9 units): students must take a focused program in an applications area such as fluid mechanics, operations research, or statistics. Courses must be at the 200 level or higher, and the program of concentration must be approved by the adviser and committee. Examples of suitable courses are: AA 210A,B, 214A,B,C; EE 363, 364, 365, 378A,B; ME 238A,B, 251A,B, 269.
6. *Statistics* (3 units): students can select their course, but must get approval for their selection from their adviser.
7. *Seminar* (1 unit): students are required to regularly attend the Scientific Computing/Computational Mathematics seminar for one quarter. The seminar is held weekly during the academic year.

## DOCTOR OF PHILOSOPHY

The University's basic requirements for the Ph.D. degree (residence, dissertation, examination, etc.) are discussed in the "Graduate Degrees" section of this bulletin. The following are the program's requirements:

1. Plan and successfully complete a coherent program of study covering the basic areas of Scientific Computing and Computational Mathematics. It must at least satisfy the requirements for the M.S. degree in SC/CM. It is important that the student be able to exhibit depth in some area of application. The student's adviser has the primary responsibility for the adequacy of the program, which must meet the approval of the SC/CM Committee.
2. To be admitted to candidacy for the Ph.D. degree, a student must have successfully completed 27 units of graduate courses (200 level and above) and at least a 3.3 GPA in the courses. In addition, a student must pass a qualifying examination and choose a thesis adviser. The qualifying exam is set twice a year, in September and June. Students entering in September may take the exam immediately, but must take it by the following September. This enables a maximum of 3 attempts. The exam is in 3 parts, each of 3 hours. Broadly speaking, Part 1 is based on CME 302/CS 237A and MS&E 315, Part 2 on MATH 220A,B, and Part 3 on CS237B and CME 306/CS237C. A student who, on entering, passes a particular part is excused from taking the corresponding courses.
3. Beyond the requirements for candidacy, the student must complete a focused course of study of at least 48 units. The program should be designed to develop a deep, focused background in the research area to be pursued in the dissertation. Approval of the program must be obtained from the SC/CM Committee.
4. In addition, the student must have an adequate knowledge of a coherent area of application and must complete at least 12 units in that area.
5. The most important requirement for the Ph.D. is the dissertation. A reading committee must be selected before the student is admitted to Terminal Graduate Registration (TGR), and this committee should be frequently consulted by the student before the University oral examination. Upon completion of a draft of the dissertation, the student must pass a University oral examination in defense of the dissertation.

### PH.D. MINOR

Students wishing to obtain a Ph.D. minor in the Scientific Computing and Computational Mathematics Program should consult the department office for designation of a minor adviser. A minor in SC/CM may be obtained by completing 20 units of course work, including the sequences MATH 220A,B, MS&E 315, and CS 237A,B,C; a GPA of 3.3 or better must be maintained in these courses.

A student may choose any adviser, but approval of the director is required if the proposed adviser is not a member of Stanford Academic Council (all Stanford faculty are members). At least one member of the reading committee must be a full SC/CM faculty. If the adviser is not a full SC/CM faculty, then approval of the student's committee is required.

## COURSES

**SCCM 137. Introduction to Scientific Computing**—(Enroll in CME 108.)
*3-4 units, Win (Moin)*

**SCCM 138. Matlab and Maple for Science and Engineering Applications**—(Enroll in CS 138.)
*3-4 units (Staff) not given 2004-05*

**SCCM 220A,B. Partial Differential Equations of Applied Mathematics**—(Enroll in MATH 220A,B.)
*3 units,* **A:** *Aut (Liu),* **B:** *Win (Levy)*

**SCCM 237A,B,C. Advanced Numerical Analysis**

**SCCM 237A. Numerical Linear Algebra**— (Enroll in CME 302, CS 237A.)
*3 units, Aut (Golub)*

**SCCM 237B. Numerical Solution of Partial Differential Equations I**—(Enroll in CS 237B.)
*3 units (Staff) not given 2004-05*

**SCCM 237C. Numerical Solution of Partial Differential Equations**—(Enroll in CME 306, CS 237C.)
*3 units, Spr (Fedkiw)*

**SCCM 238. Parallel Methods in Numerical Analysis**—(Enroll in CME 342.)
*3 units, Spr (Alonso)*

**SCCM 315. Numerical Optimization** —(Enroll in CME 304.)
*3 units, Win (Murray)*

**SCCM 336. Advanced Methods in Matrix Computation**—(Enroll in CME 324.)
*3 units, Spr (Golub)*

**SCCM 337. Numerical Methods for Initial Boundary Value Problems**—(Enroll in CME 326.)
*3 units, Win (Gustafson)*

**SCCM 339. Topics in Numerical Analysis**—(Enroll in CS 339.)
*3 units, by arrangement (Staff)*

**SCCM 340. SCCM Consulting Workshop**
*1-3 units, Aut, Win, Spr, Sum (Murray)*

**SCCM 398. Curricular Practical Training**—Provides students with on-the-job training under the guidance of experienced, on-site supervisors. Students must register the quarter after their training. Students receive credit and a grade after submitting a concise report detailing work activities, problems worked on, and key results. Prerequisite: written consent of adviser.
*1 unit, Aut, Win, Spr, Sum (Staff)*

**SCCM 399. Independent Project**
*1-15 units, Aut, Win, Spr, Sum (Staff)*

**SCCM 499. Advanced Reading and Research**—Prerequisites: majoring in SC/CM; consent of adviser.
*1-15 units, Aut, Win, Spr, Sum (Staff)*

**SCCM 531. Numerical Analysis/Scientific Computing Seminar**—(Enroll in CME 500.)
*1 unit, Aut, Win, Spr (Staff)*