COLLEGE OF ENGINEERING

ADMINISTRATION

John E. Hopcroft, dean

Michael S. Isaacson, associate dean for research and graduate studies

Kenneth C. Hover, associate dean for undergraduate programs

Mark K. Spiro, associate dean for administration

Deborah Cox, assistant dean for student services

Marsha Pickens, assistant dean for alumni affairs and development

FACILITIES AND SPECIAL PROGRAMS

Most of the academic units of the College of Engineering are on the Joseph N. Pew, Jr. Engineering Quadrangle. Facilities for applied and engineering physics are located in Clark Hall on the College of Arts and Sciences campus, and facilities for agricultural and biological engineering are centered in Riley-Robb Hall on the campus of the New York State College of Agriculture and Life Sciences.

Special university and college facilities augment the laboratories operated by the various engineering schools and departments, and special centers and programs contribute to opportunities for study and research.

Cornell programs and centers of special interest in engineering include the following:

Center for Applied Mathematics. A cross-disciplinary center that administers a graduate program.

Center for Manufacturing Enterprise. A joint venture of Cornell, industrial organizations, and the federal government to encourage the development and implementation of modern manufacturing systems.

Center for Radiophysics and Space Research. An interdisciplinary unit that facilitates research in astronomy and the space sciences.

Center for Theory and Simulation in Science and Engineering. A supercomputer facility used for advanced research in engineering and the physical and biological sciences.

Cornell Electronic Packaging Alliance. A cooperative venture involving Cornell and several corporations in the areas of computing and microelectronics, organized to undertake precompetitive, interdisciplinary research in electronic packaging.

Cornell High Energy Synchrotron Source (CHESS). A high-energy synchrotron radiation laboratory operated in conjunction with the university's high-energy storage ring. Current research programs at CHESS are in areas of structural biology, chemistry, materials science, and physics.

Cornell Nanofabrication Facility (part of the National Science Foundation funded National Nanofabrication Users Network). A center that provides equipment and services for research in the science, engineering, and technology of nanometer scale structures for electronic, chemical, physical, and biological applications.

Cornell Waste Management Institute. A research, teaching, and extension program within the Center for Environmental Research that addresses the environmental, technical, and economic issues associated with solid waste; one facility sponsored by the institute is the Combustion Simulation Laboratory in the Sibley School of Mechanical and Aerospace Engineering.

Institute for the Study of the Continents. An interdisciplinary organization that promotes research on the structure, composition, and evolution of the continents.

Laboratory of Plasma Studies. A center for interdisciplinary research in plasma physics and lasers.

Materials Science Center. An interdisciplinary facility with substantial support from the National Science Foundation, providing sophisticated scientific measurement and characterization equipment.

National Astronomy and Ionosphere Center. The world's largest radio-radar telescope facility, operated by Cornell in Arecibo, Puerto Rico.

National Earthquake Engineering Research Center. A facility recently established by the National Science Foundation and a group of universities in New York State to study response and design of structures in earthquake environments.

National Institutes of Health/National Science Foundation Developmental Resource in Biophysical Imaging and Optoelectronics. A resource that develops novel measurement and optical instrumentation for solving biophysical problems.

Power Systems Engineering Research Center. A research and instructional program centered in a laboratory that has a complete real-time model of an electric power system.

Program of Computer Graphics. An interdisciplinary research center that operates one of the most advanced computer-graphics laboratories in the United States.

Program on Science, Technology, and Society. A cross-disciplinary unit that sponsors courses and promotes research on the interaction of science, technology, and society.

SRC Program on Microscience and Technology. A center sponsored by the Semiconductor Research Corporation to promote research essential to the development of VLSI devices and circuits.

Ward Laboratory of Nuclear Engineering. Irradiation, isotope production, and activation analysis facilities for interdisciplinary research.

The programs listed on this page are sponsored by College of Engineering units and several are industry affiliated. These are in the areas of injection molding, computer science, materials science, geologic study of the continents, and nanometer scale structures.

DEGREE PROGRAMS

Cornell programs in engineering and applied science lead to the degrees of Bachelor of Science, Master of Engineering (with field designation), Master of Science, and Doctor of Philosophy.

General academic information concerning the Bachelor of Science degree is given here under the heading "Undergraduate Study." Curricula for major studies are described under the various academic areas.

Programs leading to the Master of Science and Doctor of Philosophy degrees are administered by the Graduate School. They are described in the *Announcement of the Graduate School* and the special announcement *Graduate Study in Engineering and Applied Science.* The professional Master of Engineering programs and cooperative programs with the Johnson Graduate School of Management are described below.

UNDERGRADUATE STUDY

Bachelor of Science (B.S.) degrees are offered in the following areas:*

Agricultural and Biological Engineering†

Chemical Engineering

Civil Engineering

College Program

Computer Science

Electrical Engineering

Engineering Physics

Geological Sciences

Materials Science and Engineering

Mechanical Engineering

Operations Research and Engineering

Students in the College of Engineering begin their undergraduate studies in the Common Curriculum, which is administered by the faculty members of the College Curriculum Governing Board (CCGB) through the associate dean for undergraduate programs and the Engineering Advising office. Subsequently most students enter *field* programs, which are described separately for each academic area. Criteria for entrance into the field programs are described in the section titled "Affiliation with a Field Program." Alternatively students may enter the *College Program* (described below), which permits them to pursue a course of study adapted to individual interests.

Students interested in bioengineering may arrange a suitable curriculum through a bioengineering option within one of the field programs or through the College Program.

Information about the bioengineering option is available in the Engineering Advising office, 167 Olin Hall. Students interested in environmental engineering and science may pursue the environmental option offered by the School of Civil and Environmental Engineering, the major offered by the Department of Agricultural and Biological Engineering, or the Science of Earth Systems (SES) option offered by the Department of Geological Sciences. Double majors combining environmental science and engineering are feasible.

*Agricultural and biological engineering, chemical engineering, civil engineering, electrical engineering, engineering physics, materials science and engineering, mechanical engineering, and operations research and engineering are accredited by the Engineering Accreditation Commission of the Accreditation Board for Engineering and Technology.

†To major in agricultural and biological engineering students normally enroll in the College of Agriculture and Life Sciences for the first and second years, and jointly in that college and the College of Engineering for the third and fourth years. However, students enrolled in the College of Engineering for the first two years may affiliate with the field of agricultural and biological engineering and become jointly enrolled in the Colleges of Agriculture and Life Sciences and Engineering for the third and fourth years.

Requirements for Graduation

To receive the Bachelor of Science degree, students must meet the requirements of the Common Curriculum, as set forth by the College of Engineering, including the requirements of the field program, as established by the school or department with which they become affiliated. Students must meet the Common Curriculum as explained below. (Further explanation of the revised Common Curriculum and field flow charts are provided in the 1997–98 edition of the *Engineering Undergraduate Handbook.*)

Course Category	*Credits*
1) Mathematics	16
2) Physics (depending on field)	8–12
3) Chemistry (depending on field)	4–8
4) Freshman writing seminar*	6
5) Computer programming†	4
6) Engineering distribution (3 courses)	
a. One Introduction to Engineering (ENGRI)	3
b. Two other engineering distribution courses (ENGRD)	6
7) Liberal studies distribution (6 courses)	18 (min.)
8) Approved electives	6
9) Field program	
a. Field required courses	30 cr. min.
b. Field approved electives	9
c. Courses outside the field	9

*One writing-intensive technical course or a course in technical or scientific writing must also be taken; this course may simultaneously satisfy some other requirement.

†One approved course in computing applications must also be taken; this course may simultaneously satisfy some other requirement, such as an engineering distribution course, an approved elective, or a field program course.

From 123 to 129 credit hours are required for graduation; the specific number of required credit hours will vary depending on which field program is chosen. (See field curricula for specific field requirements.) Two terms of physical education must be taken in the freshman year and students must demonstrate proficiency in swimming to satisfy a university requirement.

Mathematics

The normal program in mathematics includes MATH 191 (or 193), 192, 293, and 294. Every student must attain a grade of at least C- in MATH 191 (or 193), 192, 293, and 294, or other courses that may be approved as substitutes for these courses. If this requirement is not met the first time a course is taken, the course must be repeated immediately and a satisfactory grade attained before the next course in the sequence may be taken. Courses that are taken a second time in order to meet this requirement do not yield additional credit toward a degree.

Physics

The normal program in physics includes PHYS 112, 213, and 214 or the corresponding honors courses (PHYS 116, 217, and 218). Engineering students are required to have attained a minimum grade of C- in MATH 191 or equivalent before taking PHYS 112. The same minimum grade is required in each subsequent mathematics course before taking the physics course for which it is a prerequisite (e.g., C- in MATH 192 before taking PHYS 213, or C- in MATH 293 before taking PHYS 214). Students in the field programs of ABEN, CHEME, CEE (environmental track), or OR&IE may substitute CHEM 208 for PHYS 214.

Chemistry

CHEM 211 or 207 is required for all students.

CHEM 211 is a course designed for students who do not intend any further study in chemistry and may be taken either in the fall or spring of the freshman year or the first semester of their sophomore year if they take PHYS 112 or 213 in their freshman year.

In general, students intending to affiliate with the following departments and schools should take CHEM 211: applied and engineering physics, civil engineering (not students in the environmental engineering option), computer science, electrical engineering, material science and engineering, mechanical and aerospace engineering, and operations research and industrial engineering. Students considering chemical engineering must take CHEM 207 in the fall of their freshman year, to be followed by CHEM 208 in the spring term. All students considering the environmental concentration in civil engineering, geological sciences, or a health-related career such as medicine should take the CHEM 207–208 sequence.

Freshman Writing Seminars

Each semester of their freshman year, students choose a freshman writing seminar from among more than one hundred courses offered by over thirty different departments in the humanities, social sciences, and expressive arts. These courses offer the student practice in writing English prose. They also assure beginning students the benefits of a small class.

Technical Writing

In addition to the two Freshman Writing Seminars required, engineering students must take a course that includes a significant amount of technical and scientific writing. This course may be used to satisfy another graduation requirement. A student can fulfill the technical writing requirement by enrolling in an engineering course specifically designed to include a writing-intensive component or by taking a course in technical or scientific writing. Courses that currently satisfy this requirement are ENGRD/A&EP 264, CHEM E 432, COMM 352*, COMM 360*, COMM 363*, ELE E 215, ENGRC 350*, ENGRC 435*, M&AE 427, MS&E 435, and MS&E 443–444 if both courses are taken. Students participating in the Engineering Cooperative Program may also arrange for a writing-intensive co-op experience to satisfy this requirement. Updated information on these approved courses may be obtained from the Engineering Advising office, 167 Olin Hall.

*Please note that enrollments are limited in COMM and ENGRC writing courses.

Computing

In either the first or second term of their freshman year, students normally take COM S 100, Introduction to Computer Programming. Before graduation they must take an additional course with a significant amount of computing applications; this course may also be used to meet another graduation requirement. Courses that satisfy this requirement are ABEN 453, ABEN 475, ENGRD/COM S 211 or 212, ENGRD/COM S 222, ENGRD/CEE 241, ENGRD/A&EP 264, ELE E 423, M&AE 389, M&AE 489, M&AE 575, M&AE 578, and M&AE 670. The recommended choice for students intending to enter the Field Program in Engineering Physics is ENGRD 264; in Chemical Engineering, ENGRD 211, 222 or 241; in Civil Engineering, ENGRD 241; in Computer Science, ENGRD 211 or 212; in Electrical Engineering, ENGRD 211; in Mechanical Engineering, M&AE 389, M&AE 489, M&AE 575, or M&AE 670; and in Operations Research and Engineering, ENGRD 211.

Engineering Distribution

Three engineering distribution courses (9 credits) are required. One course must be an Introduction to Engineering Course (designated by ENGRI) and is to be taken by the student during their freshman year. The Introduction to Engineering course will introduce students to the engineering process and provide a substantive experience in an open-ended problem solving context. See the Introduction to Engineering Course listing for current course offerings.

The other two distribution courses must be selected from two different categories listed below. A student may use any one of the possible substitutions described.

1) *Scientific computing*
ENGRD 211, Computers and Programming
ENGRD 212, Structure and Interpretation of Computer Programs
ENGRD 222, Introduction to Scientific Computing
ENGRD 241, Engineering Computation

2) *Materials science*
ENGRD 261, Introduction to Mechanical Properties of Materials

3) *Mechanics*
ENGRD 202, Mechanics of Solids
ENGRD 203, Dynamics

Students in the Field Program in Engineering Physics may substitute A&EP 333 for ENGRD 203.

4) *Probability and statistics*
ENGRD 270, Basic Engineering Probability and Statistics

Students in the Field Program in Electrical Engineering may substitute ELE E 310 for ENGRD 270. Students in the Field Program in Engineering Physics may substitute ELE E 310 or MATH 471 for ENGRD 270. Students in the Field Programs in Civil Engineering and Agricultural and Biological Engineering may substitute CEE 304 for ENGRD 270.

5) *Electrical sciences*
ENGRD 210, Introduction to Electrical Systems
ENGRD 231, Introduction to Digital Systems
ENGRD 264, Computerized-Instrumentation Design

6) *Thermodynamics and energy balances*
ENGRD 219, Mass and Energy Balances
ENGRD 221, Thermodynamics

7) *Earth and life sciences*
ENGRD 201, Introduction to the Physics and Chemistry of the Earth
ENGRD 250, Engineering Applications in Biological Systems

8) *Biology and chemistry*
BIO G 101 and 103, Biological Sciences, Lecture and Laboratory
BIO G 105, Introductory Biology
BIO G 107, General Biology (summer only)
CHEM 389, Physical Chemistry I

Some fields require a specific engineering distribution course as a prerequisite for the upperclass course sequence. These requirements are:

Chemical Engineering: ENGRD 219

Civil Engineering: ENGRD 202, and ENGRD 219 (for environmental option)

Computer Science: ENGRD 211 or ENGRD 212

Electrical Engineering: ENGRD 231 (co-enrollment in ELE E 232 strongly recommended)

Materials Science and Engineering: ENGRD 261

Mechanical Engineering: ENGRD 202

Operations Research and Engineering: ENGRD 270

Liberal Studies Distribution

The six required liberal studies courses (totaling at least 18 credits) may be chosen from approved courses in four categories: (a) humanities or history, (b) social sciences, (c) foreign languages, and (d) expressive arts. (No freshman seminar may be used to meet the liberal studies requirement.)

- At least two courses must be chosen from category (a).
- No more than 3 credits toward this requirement may be taken in category (d).
- At least two courses in either category (a) or (b) must be from the same field of study. One of these courses must be at or above the 200-level or be an explicit prerequisite of the other.

Following each category is a list of approved courses. Every effort has been made to keep the lists up to date, but errors sometimes occur. Students who wish to use a course that seems to fit the category description but is not listed should contact the Engineering Advising office.

a) Humanities or History

American Studies 101, 201, 202

Architecture 131, 132, 181, 182

Art 317, 318

Africana Studies 202, 204, 205, 211, 280, 285, 304, 310, 361, 370, 381, 422, 425, 431, 432, 435, 455, 475, 483

Anthropology 290, 451, 452, 453, 455

Archeology (courses in Old World Archeology and 493)

Asian Studies (courses in Asian art, literature, religion or cultural history)

Biology and Society 206

Classics (all courses except 285, 356, 360, 361 and language courses)

Collective Bargaining, Labor Law and Labor History 100, 101, 384, 385, 386, 482, 488

Communication 426, 465

Comparative Literature (all courses)

Economics 315, 323, 324, 325, 326

Engineering; ENGRG 250, 298, 360

English (all courses except ENGL 285 and writing courses, whose numbers end in the 80s; e.g., 288, 289, 382, etc.)

French Literature (all courses)

German Literature (all courses)

History (all courses)

History of Art (all courses)

Industrial and Labor Relations Interdepartmental Course 451

International and Comparative Labor Relations 430

Italian Literature (all courses)

Jewish Studies 274, 351, 352

Labor Economics 448

Music (only introductory, music theory, and music history courses)

Natural Resources 407

Near Eastern Studies (courses listed under history, civilization, or literature)

Philosophy (all courses except courses in logic and PHIL 383)

Religious Studies 101

Russian Literature (all courses)

Science and Technology Studies 233, 433, 444, 525

Spanish Literature (all courses)

Theater Arts (only courses in Theater Studies, film analysis and history)

Women's Studies 227, 238, 251, 264, 273, 307, 341, 348, 363, 365, 366, 374, 390, 404, 406, 408, 426, 433, 444, 445, 451, 455, 474, 493

b) Social Sciences

Africana Studies 171, 172, 191, 220, 231, 271, 280, 290, 300, 301, 311, 380, 410, 420, 451, 459, 478, 479

Agricultural Economics (ARME) 100, 250, 430, 431, 432, 450, 464

Anthropology (all courses except 101 and courses in Biological and Ecological Anthropology)

Archeology (all courses except those in Methodology and Technology)

Architecture 342

Asian Studies (courses in Asian anthropology, economics, government, linguistics, or sociology)

Biology and Society 201, 301, 406, 407

City and Regional Planning 100, 101, 314, 361, 382, 404, 442

Communication 116, 120, 314, 410, 416, 420

Consumer Economics and Housing (110, 111, 247, and any course having one or more of these as a prerequisite)

Design and Environmental Analysis 150, 250

Economics (all courses except 315, 317, 318, 319, 320, 321, 326. Engineering students should generally take ECON 301–302 and *not* 101–102, unless they have had no calculus.)

Education 210, 212, 271, 311, 317, 378, 413, 477

Government (all courses)

Human Development and Family Studies (all courses)

Human Service Studies (all courses)

International and Comparative Labor Relations (all courses)

Labor Economics (all courses except 345 and 448)

Linquistics (all courses)

Natural Resources 201

Organizational Behavior (all courses)

Psychology (all courses *except* 123, 307, 322, 324, 326, 332, 350, 361, 396, 422, 425, 426, 429, 465, 470, 471, 472, 473, 475, 476, 478, 479, 492)

Rural Sociology (all courses)

Sociology (all courses)

Textiles and Apparel 245

Women's Studies 210, 218, 220, 238, 244, 277, 281, 297, 305, 321, 353, 362, 365, 366, 372, 406, 408, 425, 428, 438, 450, 454, 463, 468, 479, 480, 493

c) Foreign Language

This category includes all foreign language courses; if two or more foreign language courses are used to fulfill part of the liberal studies requirement, they must be a sequence of courses in the same language. The rules for placement and advanced placement credit in languages are those of the College of Arts and Sciences. Speakers of languages other than English may obtain up to 6 advanced placement credits equal to two courses according to these rules.

d) Expressive Arts

Africana Studies 303, 425, 430

Art (studio courses)

Biological Sciences 208, 209

Communications (all courses except 116, 120, 314, 410, 416, 420, 426, 465)

Design and Environmental Analysis 101, 102, 114

Engineering (all Engineering Communications courses, which are designated ENGRC)

English (expository and creative writing courses, whose numbers end in the 80's, e.g., 288, 289, 382, etc.)

Floriculture (courses in Freehand Drawing and Scientific Illustration)

Industrial and Labor Relations 452

Music (courses in musical performance, musical organizations and ensembles; three 1-credit courses equals one course)

Theater Arts (all courses except those listed in category (a) above)

Electives

- Approved electives—six (6) credits required (approved by the academic adviser)

Because these courses should help develop and broaden the skills of the engineer, advisers will generally accept the following as approved electives:

1. One Introduction to Engineering course (ENGRI).
2. Engineering distribution courses.
3. Courses stressing written or oral communication.
4. Upper-level engineering courses.
5. Advanced courses in mathematics.
6. Rigorous courses in the biological and physical sciences.
7. Courses in business, economics, or language (when they serve the student's educational and academic objectives).
8. Courses that expand the field program or another part of the curriculum (Note: No ROTC courses may be used as approved electives unless they are co-listed by an academic department.)

- Field approved electives—Nine (9) credits (approved by engineering field program faculty and faculty advisers). Students should refer to the Field Program curricula for descriptions of courses that meet this category.
- To ensure breadth of engineering studies, field programs will also include nine (9) hours of courses outside the field.

Social Issues of Technology

It is important for engineers to realize the social and ethical implications of their work. Consequently, in selecting their humanities, social sciences, and approved electives, students are urged to consider courses listed within the "Science and Technology Studies" undergraduate area of concentration (see Interdisciplinary Centers and Programs section). These courses may provide students with an important perspective on their studies and their future careers.

Engineering Advising Office

From the time that students enter the college as freshmen until they are affiliated with a major field or the College Program before the second term of the sophomore year, they are under the administration of the Engineering Advising office, which implements the academic policies of the College Curriculum Governing Board. The office offers general advising and counseling services and serves as the primary resource center for undergraduate students in the college. The Engineering Minority Programs office and the Women's Programs in Engineering office provide additional specialized services.

Freshman Year Requirements

By the end of the freshman year, engineering students are expected to have completed (or received credit for) the following core requirements:

- MATH 191 (or 193) and MATH 192
- Two of the following: CHEM 211, 207, 208, PHYS 112, 213, 214*
- COM S 100
- Two (2) Freshman Writing Seminars
- One (1) Introduction to Engineering course (ENGRI designation)
- Two (2) Physical Education courses

(*Students with an interest in pre-med, chemical engineering, the environmental option in civil engineering, or the science of earth systems option in geological sciences should enroll in the CHEM 207–208 sequence during their freshman year.)

Affiliation with a Field Program

Students must apply for affiliation with a field program during the first term of their sophomore year, although earlier affiliation may be granted at the discretion of the field. This is done by visiting the undergraduate field consultant's office in the field of their choice and completing the "Application for Field Affiliation" form. To affiliate with a field program, students must (1) have a 2.0 cumulative grade point average and (2) have satisfied the field's course and grade requirements as specified below:

Field Program	*Courses and Minimum Grade Requirements*
Agricultural and Biological Engineering	No more than one grade below C- in mathematics and science courses and ABEN 151 or equivalent
Applied and Engineering Physics'	2.7 GPA in all mathematics and physics courses
Chemical Engineering	No more than one grade below C- in chemistry, mathematics, physics, or chemical engineering courses and a 2.2 GPA in mathematics, science, and chemical engineering courses
Civil & Environmental Engineering	A 2.0 GPA in all engineering and science courses; for students in the civil engineering option a grade of C- in ENGRD 202, for students in the environmental option a grade of C- in ENGRD 219.
Computer Science	A grade of B- in COM S 280, ENGRD 211 or 212 and all mathematics courses
Electrical Engineering	A grade of C or better in all 200-level mathematics and physics courses, and either ELE E 210 or ENGRD 231
Geological Sciences	Good academic standing in the College of Engineering
Materials Sciences & Engineering	A grade of C in ENGRD 261
Mechanical & Aerospace Engineering	A grade of C- in mathematics and science courses and ENGRD 202
Operations Research and Engineering	A grade of C- in MATH 191 (OR 193) and 192, and a 2.0 GPA in all mathematics, science, and engineering courses (both overall and in the term immediately prior to affiliation)

Students must be affiliated or conditionally affiliated by the end of their fourth semester or they will be withdrawn from the College of Engineering, unless allowed to participate in a terminal semester.

SPECIAL PROGRAMS

College Program

Individually arranged courses of study under the College Program are possible for those well-qualified students whose educational objectives cannot be met by one of the regular field programs. Often the desired curriculum is in an interdisciplinary area. Each program is developed by the student in consultation with faculty advisers and must be approved by the College Program Committee, which is responsible for supervising the student's work.

Students apply to enter the College Program by the end of the first term of the sophomore year. A student should seek assistance in developing a coherent program from professors in the proposed major and minor subject areas. If approved, the program is the curricular contract to which the student must adhere. Normally, students applying to the

College Program should have a 3.0 cumulative grade point average.

Every curriculum in the College Program, with the exception of certain faculty-sponsored programs, must comprise an engineering major and an educationally related minor. The major may be in any subject area offered by schools or departments of the college; the minor may be in a second engineering subject area or in a logically connected nonengineering area. The combinations must clearly form an engineering education in scope and in substance and should include engineering design and synthesis as well as engineering sciences. In addition to 48 credits in the major and minor subjects, including at least 32 credits in engineering courses, each program includes the normally required courses in humanities and social sciences and approved electives.

Further information about the College Program may be obtained from the associate dean for undergraduate programs, 222 Carpenter Hall.

Important Note: Because no single standardized curriculum exists, the College Program is not accredited. College Program students who intend to seek legal licensing as a Professional Engineer should be aware that this non-accredited degree program will require additional education, work, and/or experience to qualify for eligibility to take the Fundamentals of Engineering examination.

Bioengineering Option

Students who elect this option will graduate with a B.S. degree in one of the traditional fields and with an administrative note on their transcript formally recognizing their efforts in bioengineering.

The requirements for completion of the option are four courses (12 credit hours minimum) and one credit hour of Bioengineering Seminar (ENGRG 501). These courses can simultaneously satisfy other degree requirements and are not necessarily four additional courses. These four courses must be selected from two categories: science-based courses and bioengineering courses. At least one course must be from the science-based course list and at least two from the bioengineering course list. Each student interested in the bioengineering option can request (through the Engineering Undergraduate Programs and Student Services office) a faculty consultant who will assist the student in course selection for this option. The bioengineering faculty consultant is in addition to the student's regular academic adviser.

A list of approved courses is available in the Engineering Advising office, 167 Olin Hall or in the Engineering Undergraduate Programs and Student Services office, 222 Carpenter Hall.

International Programs

All students who plan to study abroad apply through Cornell Abroad; please see the Cornell Abroad program description in the introductory section of Courses of Study.

An international perspective, sensitivity to other cultures, and the ability to read and speak a second language are increasingly important to today's engineers. In keeping with the university goals of internationalizing the curriculum, the College of Engineering encourages students to study or work abroad during their undergraduate years. For further information on these and other opportunities to add an international dimension to your undergraduate education, see the staff in the Engineering Advising office, 167 Olin Hall. Information on co-op programs abroad is available from the Engineering Professional Programs office in 148 Olin Hall.

Dual Degree Option

A special academic option, intended for superior students, is the dual degree program, in which both a Bachelor of Science and either a Bachelor of Arts or Bachelor of Fine Arts degree can be earned in about five years. Students registered in the College of Engineering, the College of Arts and Sciences, or the College of Architecture, Art and Planning may apply and, after acceptance of their application, begin the dual degree program in their second or third year. Those interested should contact the appropriate coordinators of dual degree programs at the following locations: 172 Goldwin Smith Hall (for Arts and Sciences); or 135 East Sibley (for Architecture, Art and Planning); and the associate dean for engineering undergraduate programs in 222 Carpenter Hall or an advisor in the Engineering Advising office, 167 Olin Hall.

Double Major in Engineering

The Double Major option, which makes it possible to develop expertise in two allied fields of engineering, generally requires at least one semester beyond the usual four years. Students affiliate with one field in the normal way and then petition to enter a second field before the end of their junior year. All the requirements of both fields must be satisfied. Further information is available from the Engineering Advising office, 167 Olin Hall, and the individual field consultant offices.

Engineering Communications Program

The ability to communicate effectively is an essential aspect of successful professional practice. The Engineering Communications Program offers instruction in written, oral, and visual presentation of information. Engineering Communications (ENGRC 350) and Communications for Engineering Managers (ENGRC 435) are three-credit seminars designed to give students a thorough introduction to these areas. Material from real-life engineering contexts is analyzed, and many assignments are presented as professional case studies. Students write and speak to audiences having different levels of technical expertise and deal with societal, organizational, and ethical issues in communications. These courses fulfill the college's technical writing requirement (see Requirements for Graduation). In addition to offering communications seminars, the program works with the engineering disciplines to integrate communications into technical courses. Occasionally, the program's instructors offer independent studies, projects in technical/professional communications, and courses on topics of special interest. The program awards several annual prizes for writing and oral presentation. For further information, contact the director, 465 Hollister Hall.

Engineering Cooperative Program

A special program for undergraduates in most fields of engineering is the Engineering Cooperative Program, which provides an opportunity for students to gain practical experience in industry and other engineering-related enterprises before they graduate. By supplementing course work with carefully monitored, paid jobs, co-op students are able to explore their own interests and acquire a better understanding of engineering as a profession.

Sophomores in the upper half of their class are eligible to apply for the co-op program. (Students in computer science and agricultural and biological engineering are eligible, even though they may not be registered in the College of Engineering.) Applicants are interviewed by representatives of cooperating companies and select their work assignments from any offers they receive. Those students who are offered assignments and elect to join the program usually take their fifth-term courses at Cornell during the summer following their sophomore year and begin their first co-op work assignment that fall. They return to Cornell to complete term six with their classmates and then undertake a second work assignment with the same company the following summer. Co-op students return to campus for their senior year and graduate with their class.

Further information may be obtained from the Engineering Professional Programs office, 148 Olin Hall.

MASTER OF ENGINEERING DEGREE PROGRAMS

One-year Master of Engineering (M.Eng.) programs are offered in thirteen fields. These programs are discussed in this announcement in connection with the corresponding upperclass engineering field programs because the curricula are integrated. Cornell baccalaureate engineering graduates frequently continue their studies in the M.Eng. program, although the program is also open to qualified graduates of other schools. The M.Eng. degrees and the academic fields under which they are described are listed below.

M.Eng. (Aerospace): Mechanical and Aerospace Engineering

M.Eng. (Agricultural and Biological): Agricultural and Biological Engineering

M.Eng. (Chemical): Chemical Engineering

M.Eng. (Civil & Environmental): Civil and Environmental Engineering

M.Eng. (Computer Science): Computer Science

M.Eng. (Electrical): Electrical Engineering

M.Eng. (Engineering Physics): Applied and Engineering Physics

M.Eng. (Geology): Geological Sciences

M.Eng. (Materials): Materials Science and Engineering

M.Eng. (Mechanical): Mechanical and Aerospace Engineering

M.Eng. (Engineering Mechanics): Theoretical and Applied Mechanics

M.Eng. (Nuclear): Nuclear Science and Engineering

M.Eng. (OR&IE): Operations Research and Industrial Engineering

Candidates for a professional master's degree who wish to specialize in areas related to manufacturing may avail themselves of two special programs. The manufacturing systems engineering option may be centered in any one of the fields listed above. This option is attested to by a Dean's Certificate in addition to a diploma at the time of graduation. An industrial internship program provides opportunities to combine on-campus education with off-campus industrial experience.

An M.Eng. option of potential interest to engineers from all fields is the program in engineering management, offered by the School of Civil and Environmental Engineering. This option is described in the section related to the M.Eng. (Civil & Environmental) degree. A new management option in the M.Eng. (Chemical) degree program is also available.

Cornell engineering graduates in the upper half of their class will generally be admitted to M.Eng. programs; however, requirements for admission vary by field. Superior Cornell applicants who will be, at the time of matriculation, eight or fewer credits short of a baccalaureate degree may petition for early admission. Other applicants must have a baccalaureate degree or its equivalent from a college or university of recognized standing, in an area of engineering or science that is judged appropriate for the proposed field of study. They must also present evidence of undergraduate preparation equivalent to that provided by a Cornell undergraduate engineering education, a transcript, two letters of recommendation, and a statement of academic purpose. A candidate who is admitted with an undergraduate background that is judged inadequate must make up any deficiencies in addition to fulfilling the regular course requirements for the degree. Applicants from foreign universities must submit the results of the Graduate Record Examination aptitude tests and must have an adequate command of the English language. Financial aid providing partial support is available for very highly qualified candidates, primarily those who are residents of the U.S. Industry-sponsored internships, which extend the program to two years, are also available to residents of the United States. Application forms and further information are available from the graduate field offices.

Cooperative Programs with the Johnson Graduate School of Management

Two programs culminate in both Master of Engineering and Master of Business Administration degrees. One, which Cornell students enter during their undergraduate career, makes it possible to earn the B.S., M.Eng., and M.B.A. in six years—one year less than such a program would normally require. The second program, which is available to students who already hold baccalaureate degrees from Cornell or other institutions, requires five semesters and leads to both the M.Eng. and M.B.A.

Undergraduate students at Cornell interested in the six-year program should seek advice and information from the department with whose field they intend to affiliate during their upperclass years. Information about admission to either program and about scholarship aid may be obtained from the Engineering Professional Programs office, 148 Olin Hall.

ACADEMIC PROCEDURES AND POLICIES

Advanced Placement Credit

The College of Engineering awards a significant amount of advanced placement (AP) credit to entering freshmen who demonstrate proficiency in the subject areas of introductory courses. Students can earn AP credit by receiving qualifying scores on any of the following:

(1) advanced placement examinations given and scored by the College Entrance Examination Board (CEEB); or

(2) General Certificate of Education (GCE) Advanced ("A") Level Examinations; or

(3) International Baccalaureate (IB) Higher Level Examinations; or

(4) Cornell's departmental placement examinations, given during orientation week prior to the beginning of fall-term classes.

Advanced placement credit is intended to permit students to develop more challenging and stimulating programs of study. Students who receive AP credit for an introductory course may use it in three different ways.

1) They may enroll in a more advanced course in the same subject right away.

2) They may substitute an elective course from a different area.

3) They may enroll in fewer courses, using the AP credit to fulfill basic requirements.

Acceptable Subjects and Scores for CEEB or Cornell Departmental AP Exams

The most common subjects for which AP credit is awarded in the College of Engineering, and the scores needed on qualifying tests, are listed below. AP credit is awarded only for courses that meet engineering curriculum requirements.

Mathematics: MATH 191 or 193, 192, 293, and 294 are required.

First-term math (MATH 191 or 193). AP credit may be earned by:

- a score of 3 or 4 on the CEEB BC exam, or
- a score of 4 or 5 on the CEEB AB exam, or
- a passing score on the Cornell departmental exam for first-term math.

First-year math (through MATH 192). AP credit may be earned by:

- a score of 5 on the CEEB BC exam, or
- a passing score on the Cornell departmental exam for first-year math.

Physics: PHYS 112 or 116 and 213 or 217 are required.

PHYS 112. AP credit may be earned by:

- a score of 4 or 5 on the mechanics portion of the CEEB exam, or
- a score of 5 on the CEEB B exam *only* if the student has at least one semester of AP or transfer credit in first-term mathematics at the time of matriculation, or
- a passing score on the Cornell departmental exam for PHYS 112.

Note: Students who have received credit for PHYS 112 **may not** enroll in PHYS 213 unless concurrently enrolled in MATH 293.

PHYS 213. Students, receiving a 5 on the Electricity and Magnetism portion of the C exam may choose to accept AP credit for PHYS 213 or placement in PHYS 217 with no AP credit for PHYS 213. For advice or more information contact Professor Rich Galik, the departmental representative. His telephone number is 607/255-3633.

Chemistry: CHEM 207 or CHEM 211 is required.

CHEM 207 or CHEM 211. AP credits may be earned by:

- a score of 5 on the CEEB AP exam, or
- a passing score on the Cornell departmental exam for Chemistry.

Note: Students who are successful in obtaining AP credit for CHEM 207 and who are considering majors in chemical engineering or materials science and engineering should consider enrolling in CHEM 215. Those who are offered AP credit for CHEM 207 and then elect to take CHEM 215 will also receive academic credit for CHEM 207. You may want to discuss this option with your faculty adviser.

Computing: COM S 100 is required. AP credit may be earned by:

- a score of 4 or 5 on the CEEB A or AB exam, or
- a passing score on the Cornell departmental exam for COM S 100.

Biology: Biology is not required of engineering students, although it is a popular option as an elective, especially for students who intend to pursue health-related careers. AP credit may be earned as follows:

- eight credits will be offered to students who receive a 5 on the CEEB AP exam;
- six credits will be offered to students who receive a 4 on the CEEB AP.

Those who want to study more biology should contact the Office for Academic Affairs, Division of Biological Sciences, 200 Stimson Hall, to discuss proper placement.

Freshman Writing Seminar: Two Freshman Writing Seminars (for a total of six credits) are required.

- AP credit for one Freshman Writing Seminar may be earned by a score of 5 on the CEEB AP English exam.

A score of 4 on the AP English exam will earn a student three credits in English. These three credits cannot be applied toward the Freshman Writing Seminar requirement, but can be applied toward the expressive arts category in the Liberal Studies Distribution requirement. AP credit earned in the humanities and social sciences cannot be used to fulfill the "upper level" liberal studies requirement.

Liberal Studies Distribution: Six courses beyond two Freshman Writing Seminars are required. Students may earn AP credit toward the liberal studies distribution by taking College Entrance Examination Board (CEEB) AP tests. AP credit earned in the humanities or social sciences cannot be used to fulfill the "upper level" liberal studies requirements.

Modern Languages: Students may earn AP credit for competence in a foreign language by taking the College Entrance Examination Board (CEEB) AP test or by taking the Cornell Advanced Standing Examination (CASE). Those who score 4 or 5 on the CEEB AP test are entitled to three credits. In order to qualify for the CASE exam, the student must score at least 650 on a College Placement Test (taken either in high school or at Cornell during Orientation Week). A score of 2 on the CASE entitles the student to three credits, and a score of 3 entitles the students to six credits which are equivalent to two courses. Modern language AP credits may be used to satisfy the foreign language category of the liberal studies distribution, or may meet an approved elective requirement, contingent on discussions with the faculty adviser.

Advanced Placement and Credit for International Credentials

Students who have successfully completed either a General Certificate of Education (GCE) Advanced ("A") Level Examination or an International Baccalaureate (IB) Higher Level Examination may be eligible for advanced placement credit in the College of Engineering as follows:

General Certificate of Education Advanced Level Examination (GCE "A")

Hong Kong Advanced Level examinations and the joint examination for the Higher School Certificate and Advanced Level Certificate of Education in Malaysia and Singapore—principal passes only—are considered equivalent in standard to GCE "A" Levels.

Subject	Marks	Credit
Biology	A or B	8 credits
Chemistry	A	8 credits (CHEM 207 and 208)
	B	4 credits (CHEM 207)
Mathematics	A or B	8 credits (MATH 191/193 and 192)
	C	4 credits (MATH 191/193)
Physics	A or B	4 credits for PHYS 112; 4 additional credits for PHYS 213 are granted to a combination of grades of A or B and a minimum of 8 Advanced Placement (or advanced standing) credits in mathematics.

International Baccalaureate (IB) Higher Level Examination

Subject	Marks	Credit
Biology	7	8 credits
	6	6 credits
Chemistry	6 or 7	4 credits (CHEM 207)
Mathematics	6 or 7	8 credits (engineering students must consult with the math department to determine prerequisite for placement in third-semester math course.)
Physics	6 or 7	4 credits (PHYS 112)

Note: Advanced Placement credit based on GCE or IB results may also be awarded for courses that satisfy the liberal studies requirement in the College of Engineering. In such cases, the College of Engineering follows the AP guidelines found earlier in this publication under "General Information."

General Policies for Advanced Placement

The general policies in the College of Engineering governing awards of AP credit are as follows:

1. AP credit will not be offered in any subject area without a documented examination.
2. All AP examinations are normally taken and scored before fall-term classes begin. Students who take CEEB AP tests in high school should have an official report of their scores sent directly to Cornell as soon as possible. Students who have completed either GCE "A" Level or IB Higher Level Examinations must present the original or a certified copy of their examination certificate to the Engineering Advising office, 167 Olin Hall. Those who wish to take departmental examinations do so during Orientation Week; permission to take these tests after the start of fall-term classes must be requested in a written petition to the College's Committee on Academic Standards, Petitions, and Credit (ASPAC).

A more detailed description of the college's policies concerning advanced placement credit and its use in developing undergraduate programs may be found in the pamphlet *Advanced Placement and Transfer Credit for First-Year Engineering Students*, which may be obtained from the Engineering Advising office, 167 Olin Hall.

Transfer Credit

Undergraduate students who have completed courses at recognized and accredited colleges may, under certain conditions, have credits for such courses transferred to Cornell. Such courses must represent academic work in excess of that required for the secondary school diploma. Courses deemed acceptable for transfer credit must be equivalent in scope and rigor to courses at Cornell.

- To apply for transfer credit, students must complete and submit a transfer credit form (one form for each request), accompanied by a course description. (Transfer credit forms are available from the Engineering Advising or Registrar's offices and should be submitted prior to enrollment.) An official transcript from the offering institution (bearing the institutional seal and registrar's signature) must be sent to the Engineering Registrar's office before official transfer credit will be awarded.
- To apply for transfer credit to satisfy requirements in mathematics, science, engineering courses, or Freshman Writing Seminars, a student must receive approval from the department offering an equivalent course at Cornell. The department certifying the course may require course materials, textbooks used, etc., in addition to the course description before approving the course.
- Departmental approval is not required to apply for transfer credit which satisfies liberal studies distribution requirements. The course will be reviewed for approval by a representative of the Committee on Academic Standards, Petitions, and Credit (ASPAC) in the Engineering Advising office.
- Cornell does not award credit for courses in which a student has earned a grade of less than C; schools and departments may stipulate a higher minimum grade.
- College courses completed under the auspices of cooperative college and high school programs will be considered for advanced placement credit only if students demonstrate academic proficiency by taking the appropriate AP or Cornell departmental placement examination, as described in the Advanced Credit section.
- After matriculation, no more than 18 credits of transfer or Cornell extramural credit may be used to satisfy bachelor's degree requirements. Summer session courses taken at Cornell are not considered transfer credits.
- Transfer students may transfer up to 36 credits for each year spent in full-time study at another institution, provided that the courses are acceptable for meeting graduation requirements. No more than 72 transfer credits may be used to meet graduation requirements.
- A more detailed description of the college's regulations governing transfer credit may be found in the pamphlet, *Advanced Placement and Transfer Credit for First-Year Engineering Students*, as well as *The Engineering Undergraduate Handbook*, both available from the Engineering Advising office, 167 Olin Hall.

Academic Standing

Full-time students are expected to remain in good academic standing. The criteria for good standing change somewhat as a student progresses through the four years of the engineering curriculum. At all times, the student must be making adequate progress toward a degree, but what this actually means varies from field to field.

Requirements for freshman engineering students to be in good standing at the end of the first semester are as follows. Failure to meet these standards will result in a review by the Committee on Academic Standards, Petitions, and Credit (ASPAC), and the actions of warning, stern warning, required leave of absence, or withdrawal from the College of Engineering may be taken.

1. at least 12 credits passed, including at least two courses from mathematics, science, and/or engineering;
2. a C- or better in the mathematics course;
3. a semester average of 2.0 or higher;
4. no F, U, or INC grades.

Requirements for second-semester freshman and first-semester sophomores to be in good standing are as follows. Failure to meet these standards will result in a review by the Committee on Academic Standards, Petitions, and Credit (ASPAC), and the actions of warning, stern warning, required leave of absence, or withdrawal from the College of Engineering may be taken.

1. at least 14 credits passed in courses that meet engineering degree requirements;
2. a C- or better in the mathematics course, if one was taken;
3. a semester average of 2.0 or higher;
4. no F, U, or INC grades.

Academic Progress

The total number of credits required for graduation range from 123 to 129, depending upon the field program. Therefore, an average semester credit load ranges from approximately 15 to 16 credits.

Because mathematics is pivotal to the study and practice of engineering, students must earn a grade of C- or better in MATH 191 (or 193), 192, 293, and 294. Those who fail to meet this standard are allowed to repeat a course once, in the following semester. Failure to achieve at least a C- the second time will generally result in dismissal from the engineering program. Physics and advanced mathematics courses often have mathematics prerequisites, and having to repeat the prerequisite course may delay your progress in the physics and mathematics curricula.

Dean's List

Dean's List citations are presented each semester to engineering students with exemplary academic records. The criteria for this honor, which are determined by the dean of the college, are a term average of 3.25 (without rounding) or higher with no failing, unsatisfactory, missing, or *incomplete* grades (even in physical education) and 12 credits or more of **letter grades**. Students may earn Dean's List status retroactively if they meet these criteria after making up incompletes according to college rules.

Graduating with Distinction and Honors Program

Graduating with Distinction

Meritorious students graduating with a Bachelor of Science degree from the College of Engineering may also be designated *cum laude, magna cum laude*, or *summa cum laude. Cum laude* requires a GPA ≥ 3.50 (either overall or for the last four full-time semesters in Engineering); *magna cum laude* requires a GPA ≥ 3.75 (based on all credits taken at Cornell); and *summa cum laude* requires a GPA ≥ 4.0 (based on all credits taken at Cornell). Note: All GPA calculations are minimums and are not rounded.

Field Honors Program

To be eligible for field honors, a student must enter a program with and maintain a cumulative GPA of ≥ 3.50. (i.e., the student must also be eligible for one of the three *cum laude* distinctions.) If the student's major field has an approved honors program and both the GPA and program requirements are fulfilled, the faculty of the field may recommend that a student graduate with the additional diploma and transcript notation of "With Honors." For more specific information, see the field program outline in this catalog.

S-U Grades

Many courses offered by the university may be taken either for a letter grade or for an S-U (satisfactory or unsatisfactory) grade designation. Under the S-U option, students earning the letter grade equivalent of C- or better in a course will receive a grade of S; those earning less than C- receive a grade of U. (Any course in which a U grade is received does not count toward graduation requirements.)

Engineering students may choose to receive an S-U grade option under the following conditions:

- The course in question must be offered with an S-U option.
- The student must have previously completed at least one full semester of study at Cornell.
- The proposed S-U course must count as either a liberal studies distribution or an approved elective in the engineering curriculum.
- Students may only elect to enroll S-U in one (1) course each semester in which the choice between letter grade and S-U is an option. (Additional courses offered "S-U only" may be taken in the same semester as the "elected S-U" course.)

The choice of grading option for any course is initially made during the pre-enrollment period. Grading options may be changed, however, by submitting a properly completed add/drop form to the Engineering Registrar by the end of the third week of classes. After this deadline, the grading option may not be changed, nor will a student be permitted to add a course in which they were previously enrolled (in the current semester) under a different grade option.

Residence Requirements

Candidates for an undergraduate degree in engineering must spend at least four semesters or an equivalent period of instruction as full-time students at Cornell. They must also spend at least three semesters of this time affiliated with an engineering field program or with the College Program.

Students who are voluntarily not enrolled at Cornell as full-time students may take individual courses extramurally through the School of Continuing Education and Summer Sessions. Students who have been required to take time off are permitted to register for courses extramurally only with the approval of their field (or the college, for unaffiliated students). No more than 18 credits earned through extramural study or acquired as transfer credit (or a combination thereof) may be used to satisfy the requirements for the bachelor's degree in engineering.

Degree candidates may spend periods of time studying away from the Cornell campus with appropriate authorization. Information on programs sponsored by other universities and on procedures for direct enrollment in foreign universities is available at the Cornell Abroad office, 474 Uris Hall. Programs should be planned in consultation with the staff of the Engineering Advising office, who can provide information on credit-evaluation policies and assist in the petitioning process.

Transferring within Cornell

It is not uncommon for students to change their academic or career goals after matriculation in one college and decide that their needs would be better met in another college at Cornell. While transfer between colleges is not guaranteed, efforts are made to assist students in this situation.

The office responsible for assisting students with the transfer process is the Internal Transfer Division office. Students who wish to transfer out of the College of Engineering to another college at Cornell should consult initially with the Engineering Advising office.

Students who wish to transfer into the College of Engineering can apply at the Engineering Advising office—application forms are available in 167 Olin Hall. Students who would enter the college as second-semester sophomores or later must be accepted by a field program as part of the admission process. Students who would enter as a second-semester freshman or first-semester sophomore may be accepted into the college without the requirement of field affiliation but must be sponsored by a field program.

Students who hope to transfer into engineering should take courses in mathematics, chemistry, computer science, physics, and engineering that conform to the requirements of the Common Curriculum. Interested students should discuss their eligibility with an adviser in the Engineering Advising office, 167 Olin Hall.

Leave of Absence

A leave of absence may be voluntary, medical, or required. A description of each follows:

Voluntary Leave: Students sometimes find it necessary to suspend their studies. To do this, students must petition for a leave of absence for a specified period of time and receive written approval.

Affiliated students request leave through their fields. Unaffiliated students request leave through the Engineering Advising office; the first step is an interview to establish conditions for the leave and subsequent return. Those who take a leave before affiliating with a field and while not in good standing may be given a "conditional leave." This requires them to meet specific conditions, established at the time the leave is granted, before they will be reinstated.

Leaves of absence are not generally granted for more than two years. A leave of absence granted during a semester goes into effect on the day it is requested and lasts for a *minimum of six months*. If a leave is requested after the twelfth week of a semester, the courses in which the student was registered at the time of the request are treated as having been dropped (i.e., a "W" will appear on the transcript for each course.) Students who owe money to the university are ineligible for leaves of absence. If courses taken during a leave are to satisfy Cornell degree requirements, they must be approved *in advance* through a formal transfer petition. No more than 18 credits earned while on leave can be used to meet degree requirements.

Students who intend to take a leave of absence should check with the Office of Financial Aid and Student Employment to discuss financial implications; this is especially true for those who have taken out educational loans. Medical insurance eligibility may also be affected.

To return after a leave of absence, the conditions established when the leave was granted must be satisfied, and the college must be notified in writing, at least six weeks prior to the date the student plans to return to campus.

Medical Leave: Medical leaves are granted by the college only upon recommendation by a physician from Gannett Health Center. Such leaves are granted for at least six months and up to five years with the understanding that the student may return at the beginning of any term after the medical condition in question has been corrected. In some cases students must satisfy the Gannett Health Center that the condition has been corrected before they may return. The student's academic standing will also be subject to review both at the time the leave is granted and upon the student's return.

Required Leave: A required leave of absence is imposed in cases where the academic progress of a student is so poor that continuing into the next semester does not appear prudent. An example where a leave of absence would be required might be failure in several courses in a semester. Unless the student is ahead in the curriculum, returning later to repeat the semester makes better academic sense than continuing without the necessary background. In many cases, the leave is dictated by courses that are only offered in the fall or the spring semester. Leaves are given when the probability of success is increased substantially by deferring the student's return by one semester (or, in unusual circumstances, one year).

Rejoining the College

Students wishing to rejoin the college who have not yet affiliated with a field should request permission to rejoin in a letter to the Engineering Advising office; affiliated students should contact their field office. This must be done at least six weeks before the beginning of the semester in which the student wishes to return. The letter should describe the student's activities while away from Cornell, detail any academic work completed during this time, and specify the courses the student intends to take upon return.

Withdrawal from the College

A withdrawal from the College of Engineering may be voluntary or required. Following is a description of each:

Voluntary Withdrawal: Students who voluntarily withdraw from the engineering degree program sever all connection with the college. Unaffiliated students who wish to withdraw should do so through the Engineering Advising office. Affiliated students should contact their field office. If a withdrawal is requested during the semester, courses in which the student is enrolled must be dropped in accordance with applicable regulations.

Any student who fails to register in the first three weeks of the semester, without benefit of a leave of absence or permission for study in absentia, will be deemed to have withdrawn.

Students who withdraw from the College of Engineering are eligible to apply for admission to one of the other six colleges at Cornell. The intra-university transfer process should be followed.

If students who have withdrawn subsequently wish to return, they must make a formal application for readmission. This is rarely granted. It is subject to a review of the student's academic background and depends on available space in the college and in the student's major field.

Required Withdrawal: Students are required to withdraw from the college only when their overall record indicates that they are either incapable of completing the program or not sufficiently motivated to do so. This action only withdraws them from the College of Engineering and does not, in and of itself, adversely affect their ability to transfer and complete a degree in one of the other colleges in the university.

ENGINEERING CAREER SERVICES

Individual advising and group seminars are available for students who desire assistance in career and job-search matters. Nearly 300 national companies visit the campus annually to recruit technical graduates. Additional job opportunities are posted electronically, and a state-of-the-art résumé referral service is offered for a small fee. Both undergraduate and graduate students can use these services to pursue permanent or summer employment opportunities. Further information on all services is available from the Engineering Career Services office, 201 Carpenter Hall (255-5006); http://www.career.cornell.edu/ccs.

AGRICULTURAL AND BIOLOGICAL ENGINEERING

M. F. Walter, chair; B. A. Ahner, L. D. Albright, D. J. Aneshansley, J. A. Bartsch, P. Baveye, J. R. Cooke, A. K. Datta, K. G. Gebremedhin, D. A. Haith, J. B. Hunter, L. H. Irwin, L. Jelinski, W. J. Jewell, D. B. Lund, C. D. Montemagno, J.-Y. Parlange, R. E. Pitt, N. R. Scott, T. S. Steenhuis, M. B. Timmons, L. P. Walker

Bachelor of Science Curriculum

Agricultural and Biological Engineering is at the focus of three great challenges facing humanity today: ensuring an adequate and safe food supply in an era of expanding world population; protecting and remediating the world's natural resources, including water, soil, air, energy and biodiversity; and developing engineering systems that monitor, replace, or intervene in the biology of living organisms. The undergraduate Engineering Program in the Department of Agricultural and Biological Engineering has a unique focus on biological systems, including the environment, that is realized through a combination of fundamental engineering sciences, biology, applications courses, and liberal studies. The program leads to a joint Bachelor of Science degree from the Colleges of Engineering and Agriculture and Life Sciences, and is accredited by the Engineering Accreditation Commission (EAC) of the Accreditation Board for Engineering and Technology (ABET).

Three concentrations in Agricultural and Biological Engineering are offered: Environmental Systems Engineering, Biological Engineering, and Agricultural Engineering. All of these students take courses in mathematics, computing, physics, chemistry, basic and advanced biology, fundamental engineering sciences (mechanics, thermodynamics, fluid mechanics, and transport processes), engineering applications, and design. Students select application courses in the department in areas that include bioprocessing, soil and water management, bioenvironmental and facilities engineering, bioinstrumentation, engineering aspects of animal physiology, environmental systems analysis, and waste treatment and disposal. Students select other courses in the College of Engineering that reflect their concentration, such as environmental engineering or biomedical engineering. Students planning for medical school also take organic chemistry. Throughout the curriculum, emphasis is placed on communications and teamwork skills.

Many undergraduate students participate in teaching assistantships, research assistantships, design teams, Engineering Coop, and study abroad. Students should have a strong aptitude for the sciences and mathematics and an interest in the complex social issues that surround technology.

Career opportunities cover the spectrum of private industry, public agencies, educational institutions, and graduate programs in engineering, science, medicine, law, and other fields. In recent years, graduates have developed careers in environmental consulting, biotechnology, the pharmaceutical industry, biomedical engineering, management consulting, and international agriculture.

The living world is all around us, and within us. The biological revolution of this century has given rise to a growing demand for engineers who have studied biology and the environment, who have strong math and science skills, who can communicate effectively, and who appreciate the challenges facing society. Agricultural and biological engineering is training the next generation of engineers to meet these challenges. The department is located in Riley-Robb Hall and operates specialized facilities that are among the largest and most complete of their kind in the world.

For further details see the department's undergraduate programs publication, available at 207 Riley-Robb Hall, or contact the field's advising coordinator, Professor Ron Pitt, at 255–2492.

The field program requirements are outlined below.

Basic Subjects	*Credits*
MATH 191 (or 193), 192, 293, 294, Calculus for Engineers and Engineering Mathematics	16
CHEM 211, General Chemistry, or equivalent	4
PHYS 112, 213, 214, Physics I, II, and III (CHEM 208 or organic chemistry may be substituted for PHYS 214)	12
Introductory biological sciences	6 or 8
ABEN 151, Introduction to Computing	4
ABEN 200, Undergraduate Seminar	1
Engineering distribution (two courses, including ENGRD 202, Mechanics of Solids)	6
Liberal studies (two freshman seminars and at least two courses in humanities or history)	24
Advanced and Applied Subjects	
Engineering sciences in any field (must include fluid mechanics and thermodynamics), plus ABEN 250 and 350 (Engineering Applications in Biological Systems, Bio. & Env. Transport Processes), and a minimum of four agricultural and biological engineering courses (at least 12 credits) chosen from courses numbered 450 to 495	35
Environmental, biological or agricultural sciences (at least 3 credits of biological sciences beyond the introductory level)	9
Approved electives (at least 3 credits in the College of Agriculture and Life Sciences)	6
Total (minimum)	123

Agricultural and Biological Engineering Honors Program

Eligibility

The Bachelor of Science degree with honors will be granted to students who, in addition to having completed the requirements for a bachelor's degree, have satisfactorily completed the honors program in the Department of Agricultural and Biological Engineering and have been recommended for the degree by the honors committee of the department. An honor's program student must enter with and maintain a cumulative GPA ≥ 3.50 and must be eligible for one of the *cum laude* distinctions at the time of graduation.

Content

An ABEN honors program shall consist of at least nine credits beyond the minimum required for graduation in ABEN. These nine credits shall be drawn from one or more of the following with at least four credit hours in the first category:

- A significant research experience or honors project under the direct supervision of an ABEN faculty member using ABEN 499, Undergraduate Research. A written senior honors thesis must be submitted as part of this component.
- A significant teaching experience under the direct supervision of a faculty member or as part of a regularly recognized course in the department (e.g., ABEN 151 or 250) under ABEN 498, Undergraduate Teaching.
- Advanced or graduate courses. These additional courses must be technical in nature, i.e., in engineering, mathematics, biology, chemistry and physics at the 400- and graduate level.

Note: No research, independent study, or teaching for which the student is paid may be counted toward the honors program.

Timing

All interested students must complete a written application no later than the end of the third week of the first semester of their senior year, but are encouraged to make arrangements with a faculty member during the second semester of their junior year. A student must be in the program for at least two semesters before graduation.

Procedures

Each applicant to the ABEN honors program must have an ABEN faculty advisor to supervise the honors program. A written approval of the faculty member who will direct the research is required. After the College verifies the student's grade-point average, the student will be officially enrolled in the honors program.

Master of Engineering (Agricultural and Biological) Degree Program

The program for the M.Eng. (Agricultural and Biological) degree is intended primarily for those students who plan to enter engineering practice. The curriculum is planned as an extension of an undergraduate program in agricultural and biological engineering but can accommodate graduates of other engineering disciplines. The curriculum consists of 30 credits of courses intended to strengthen the students' fundamental knowledge of engineering and develop their design skills. At least three of the required 30 credits are earned for an engineering design project that culminates in a written and oral report.

A candidate for the M.Eng.(Agricultural and Biological) degree may choose to concentrate in one of the subareas of agricultural and biological engineering or take a broad program without specialization. The subareas include biological engineering, energy, environmental engineering, environmental management, food engineering, international agriculture, local roads, machine systems, soil and water engineering, and structures and environment. Elective courses are chosen from among engineering subject areas relevant to the student's interests and design project. Courses in technical communication, mathematics, biology, and the physical sciences may also be taken as part of a coherent program. Master of Engineering students in agricultural and biological engineering can qualify for the Dean's Certificate in energy, manufacturing, or bioengineering by choosing their design project and a number of electives from the designated topic areas. More information is available from the ABEN Student Services office, 207 Riley Robb Hall (255–2173), or by e-mail at abengradfield@cornell.edu.

APPLIED AND ENGINEERING PHYSICS

R. A. Buhrman, director; M. S. Isaacson, associate director for undergraduate studies; J. D. Brock, director of graduate studies, B. W. Batterman, T. A. Cool, H. G. Craighead, H. H. Fleischmann, A. L. Gaeta, V. O. Kostroun, B. R. Kusse, R. V. E. Lovelace, J. Silcox, W. W. Webb, F. W. Wise; adjunct faculty: D. H. Bilderback; senior research associate: E. J. Kirkland

Bachelor of Science Curriculum

The undergraduate engineering physics curriculum is designed for students who want to pursue careers of research or development in applied science or advanced technology and engineering. Its distinguishing feature is a focus on the physics and mathematics fundamentals, both experimental and theoretical, that are at the base of modern engineering and research and have a broad applicability in these areas. By choosing areas of concentration, the students may combine this physics base with a good background in a conventional area of engineering or applied science.

The industrial demand for engineering physics graduates with baccalaureates is high, and many students go directly to industrial positions where they work in a variety of areas that either combine, or are in the realm of, various more conventional areas of engineering. Recent examples include bioengineering, computer technology, electronic-circuit and instrumentation design, energy conversion, environmental engineering, geological analysis, laser and optical technology, microwave technology, nuclear technology, software engineering, solid-state-device development, technical management, and financial consulting. A number of our graduates go on for advanced study in all areas of basic and applied physics, as well as in a diverse range of areas in advanced science and engineering. Examples include applied physics, astrophysics, atmospheric sciences, biophysics, cell biology, computer science and engineering, electrical engineering, environmental science, fluid mechanics, geotechnology, laser optics, materials science and engineering, mechanical engineering, medical physics, mathematics, medicine, nuclear engineering, oceanography, and physics. The undergraduate program can also serve as an excellent preparation for medical school, business school, or specialization in patent law.

The engineering physics program fosters this breadth of opportunity because it both stresses the fundamentals of science and engineering and gives the student direct exposure to the application of these fundamentals. Laboratory experimentation is emphasized, and ample opportunity for innovative design is provided. Examples are ENGRI 110, The Laser and Its Applications in Science, Technology, and Medicine (a freshman Introduction to Engineering course); ENGRD/A&EP 264, Computer-Instrumentation Design (a recommended sophomore engineering distribution course); A&EP 330, Modern Experimental Optics (a junior/senior course); A&EP 363, Electronic Circuits (a sophomore/junior course); PHYS 410, Advanced Experimental Physics; and A&EP 438, Computational Engineering Physics (a senior computer laboratory).

Undergraduates who plan to enter the Field Program in Engineering Physics are advised to arrange their Common Curriculum with their developing career goals in mind. Students are also encouraged to take PHYS 112 or PHYS 116 during their first semester (if their advanced placement credits permit) and are recommended to satisfy the computing applications or technical writing requirement with the engineering distribution course ENGRD 264. Engineering physics students need to take only two engineering distribution courses, since A&EP 333, which they take in their junior year, counts as a third member of this category. Engineering Physics students are advised to take A&EP 363 in the spring semester of the sophomore year. Students with one semester of advanced placement in math, who have received a grade of A- or better in MATH 192, may wish to explore accelerating their mathematics requirements so as to enroll in A&EP 321 and 322 in the sophomore year. For advice on this option, consult with the A&EP associate director.

In addition to the requirements of the Engineering Common Curriculum,* the upperclass course requirements of the field program are as follows:

Course	*Credits*
A&EP 333, Mechanics of Particles and Solid Bodies	4
A&EP 355, Intermediate Electromagnetism	4
A&EP 356, Intermediate Electrodynamics	4
A&EP 361, Introductory Quantum Mechanics	4
A&EP 363, Electronic Circuits	4
A&EP 423, Statistical Thermodynamics	4
A&EP 434, Continuum Physics	4
PHYS 410, Advanced Experimental Physics	4
A&EP 321, Mathematical Physics I; or MATH 421 (applied mathematics)	4
A&EP 322, Mathematical Physics II; or MATH 422 (applied mathematics)	4
Applications of quantum mechanics†	3 or 4
Four technical electives‡	12–16
A third field approved elective (in addition to the two required by the Common Curriculum)	3

Total field credits=58 credit hours minimum.

*The Engineering Common Curriculum allows students to take only 4 courses each semester of their freshman year if they so desire. This course load is fully consistent with the requirements of the EP major, but entering students with strong preparation are encouraged to consider taking an additional course during one or both semesters of the freshman year so that they may have additional flexibility in developing a strong, individualized educational program in their latter years, and for best maintaining such options as a semester or year abroad, or early graduation.

†Some courses (though the list is not all-inclusive) that will satisfy this requirement are PHYS 444, Nuclear and High-Energy Particle Physics; PHYS 454, Introductory Solid-State Physics; A&EP 438, Computational Engineering Physics; A&EP 440, Quantum and Nonlinear Optics; A&EP 609, Nuclear Physics for Applications; ELE E 430, Lasers and Optical Electronics; and ELE E 531, Quantum Electronics I.

‡If a scientific computing course was not selected as an engineering distribution course, one of these technical electives may be needed to satisfy the computing applications requirement. For students going on to graduate school a third course in mathematics is recommended.

Areas of concentration. A distinctive aspect of the Engineering Physics curriculum is the strong opportunity it provides students to develop individualized programs of study to meet their particular educational and career goals. These can include the pursuit of dual majors or the development of a broad expertise in one or more of a number of advanced technical and scientific areas. With at least seven technical and approved electives in the sophomore, junior, and senior years, Engineering Physics majors are encouraged to work closely with their adviser to develop a coherent academic program that is in accordance with those goals. For those students who look toward an industrial position after graduation, these electives should be chosen to widen their background in a specific area of practical engineering. A different set of electives can be selected as preparation for medical, law, or business school. For students who plan on graduate studies, the electives provide an excellent opportunity to explore upper-level and graduate courses, and to prepare themselves particularly well for graduate study in any one of a number of fields. Various programs are described in a special brochure available from the School of Applied and Engineering Physics, Clark Hall. Students interested in these options are advised to consult with their EP adviser, a professor active in their area of interest, or with the associate director of the school, Professor Michael S. Isaacson.

Electives need not be all formal course work: Qualified students are encouraged to undertake independent study under the direction of a member of the faculty (A&EP 490). This may include research or design projects in areas in which faculty members are active.

The variety of course offerings and many electives provide a sizable flexibility in scheduling. If scheduling conflicts arise, the school may allow substitution of courses nearly equivalent to the listed required courses.

The Engineering Physics program requires that a minimum GPA of 2.7 (B-) be attained in all physics and mathematics courses taken by a student before entering the Engineering Physics field unless approval is obtained from the A&EP associate director. To remain in good standing in the field, the engineering physics student is expected to pass every course for which he or she is registered, to earn a grade of C- or better in specifically required courses, and to attain each semester a grade-point average for that semester of at least 2.3.

Engineering Physics Honors Program

Eligibility

The Bachelor of Science degree with honors will be conferred upon those students who, in addition to having completed the requirements for a bachelor degree, have satisfactorily completed the honors program in the Department of Engineering Physics and have been recommended for the degree by the honors committee of the department. An honors program student must enter with and maintain a cumulative GPA ≥ 3.50 and must be eligible for one of the *cum laude* distinctions at the time of graduation.

Content

The student must

1. Complete at least eight credits of field approved electives at the 400-level or higher and receive a minimum grade of an A- in each of the courses taken to fulfill this eight-credit requirement. These eight credits are in addition to the credits obtained by completing the senior thesis or special project requirement as discussed in item 2.
2. Enroll in A&EP 490 or an equivalent course over two semesters for the purpose of completing an independent research project or senior thesis under the supervision of a Cornell engineering or science faculty member. The minimum enrollment is to be two credits in the first semester and four credits in the second. The level of work required for a successful completion of this project or thesis is to be consistent with the amount of academic credit granted.

Timing

All interested students must complete a written application no later than the end of the third week of the first semester of their senior year, but are encouraged to make arrangements with a faculty member during the second semester of their junior year. A student must be in the program for at least two semesters before graduation.

Procedures

Before enrolling in A&EP 490, or the equivalent, the honors candidate must submit a brief proposal outlining the topic and scope of the proposed project or thesis and a faculty supervisor's written concurrence to the associate director for undergraduate studies. This proposal will be reviewed by the A&EP Honors Committee and either approved or returned to the candidate to correct deficiencies in the proposal. The proposed research project or senior thesis is to consist of a research, development, or design project and must go beyond a literature search. The final steps in completing the honors project are a written and oral report. The written report is to be in the form of a technical paper with, for example, an abstract, introduction, methods section, results section, conclusions section, references, and figures. This report will be evaluated by the faculty supervisor and the chair of the A&EP Honors Committee. Following the completion of the written report, an oral report is to be presented to an audience consisting of the faculty supervisor, the chair of the Honors Committee and at least one other departmental faculty member, along with the other honors candidates. The final research project course grade will be assigned by the faculty supervisor, following the oral presentation and after consultation with the chair of the Honors Committee. A minimum grade of A- is required for successful completion of the honors requirement.

Master of Engineering (Engineering Physics) Degree Program

The M.Eng.(Engineering Physics) degree may lead directly to employment in engineering design and development or may be a basis for further graduate work. Students have the opportunity to broaden and deepen their preparation in the general field of applied physics, or they may choose the more specific option of preparing for professional engineering work in a particular area such as laser and optical technology, nanostructure science and technology, device physics, materials characterization, or software engineering. A wide latitude is allowed in the choice of the required design project.

One example of a specific area of study is solid-state physics and chemistry as applied to nano-structure science and technology. Core courses in this specialty include the micro-characterization of materials (A&EP 661) and the microprocessing and microfabrication of materials (A&EP 662). The design project may focus on such areas as semiconductor materials, device physics, nanostructure technology, or optoelectronics. Another area of study may be applied optics where core courses can be chosen from applied physics, electrical engineering, and physics.

Each individual program is planned by the student in consultation with the program chair. The objective is to provide a combination of a good general background in physics and introductory study in a specific field of applied physics. Candidates may enter with an undergraduate preparation in physics, engineering physics, or engineering. Those who have majored in physics usually seek advanced work with an emphasis on engineering; those who have majored in an engineering discipline generally seek to strengthen their physics base. Candidates coming from industry usually want instruction in both areas. All students granted the degree will have demonstrated competence in an appropriate core of basic physics; if this has not been accomplished at the undergraduate level, subjects such as electricity and magnetism, or classical, quantum, and statistical mechanics should be included in the program.

The general requirement for the degree is a total of 30 credits for graduate-level courses or their equivalent, earned with a grade of C or better and distributed as follows:

1) a design project in applied science or engineering (not less than 6 nor more than 12 credits)
2) an integrated program of graduate-level courses, as discussed below (17 to 23 credits)
3) a required special-topics seminar course (1 credit)

The design project, which is proposed by the student and approved by the program chair, is carried out on an individual basis under the guidance of a member of the university faculty. It may be experimental or theoretical in nature; if it is not experimental, a laboratory physics course is required.

The individual program of study consists of a compatible sequence of courses focused on a specific area of applied physics or engineering. It is planned to provide an appropriate combination of physics and physics-related courses (applied mathematics, statistical mechanics, applied quantum mechanics) and engineering electives (such as courses in biophysics, chemical engineering, electrical engineering, materials science, computer science, mechanical engineering, or nuclear engineering). Additional science and engineering electives may be included. Some courses at the senior level are acceptable for credit toward the degree; other undergraduate courses may be required as prerequisites but are not credited toward the degree.

Students interested in the M.Eng.(Engineering Physics) degree program should contact Professor H. Craighead.

APPLIED MATHEMATICS

The Center for Applied Mathematics administers a broadly based interdepartmental graduate program that provides opportunities for study and research in a wide range of the mathematical sciences. For detailed information on opportunities for graduate study in applied mathematics, contact the director of the Center for Applied Mathematics, 657 Frank H. T. Rhodes Hall.

There is no special undergraduate degree program in applied mathematics. Undergraduate students interested in application-oriented mathematics may select an appropriate program in the Department of Mathematics or one of the departments in the College of Engineering.

A list of selected graduate courses in applied mathematics may be found in the description of the Center for Applied Mathematics, in the section "Interdisciplinary Centers and Programs."

CHEMICAL ENGINEERING

W. L. Olbricht, director; A. B. Anton, P. Clancy, C. Cohen, T. M. Duncan, J. R. Engstrom, K. E. Gubbins, P. Harriott, D. L. Koch, A. Panagiotopoulos, F. Rodriguez, W. M. Saltzman, M. L. Shuler, P. H. Steen

Bachelor of Science Curriculum

The undergraduate Field Program in Chemical Engineering comprises a coordinated sequence of courses beginning in the sophomore year and extending through the fourth year. Special programs in biochemical engineering and polymeric materials are available. Students who plan to enter the field program take CHEM 208 during the freshman year. The program for the last three years, for students who have taken an Introduction to Engineering course during the first year and entered Cornell Fall 1994 or later is as follows:

Semester 3	*Credits*
MATH 293, Engineering Mathematics	4
PHYS 213, Electricity and Magnetism	4
CHEM 389, Physical Chemistry I (engineering distribution)	4
ENGRD, Mass and Energy Balances 219 (engineering distribution)	3
Humanities or social sciences	3
Semester 4	
MATH 294, Engineering Mathematics	4
CHEM 290–391, Physical Chemistry (field)	6
ENGRD 241, 222, or 221	3
Humanities or social sciences	3
Semester 5	
CHEM 357, Introductory Organic Chemistry	3
CHEM 251, Organic Chemistry Laboratory	2
CHEME 313, Chemical Engineering Thermodynamics	4
CHEME 323, Fluid Mechanics	3
Humanities or social sciences	3
Semester 6	
Applied Science elective†	3
CHEME 301, Nonresident Lectures	1
CHEME 324, Heat and Mass Transfer	3
CHEME 332, Analysis of Separation Processes	4
CHEME 390, Reaction Kinetics and Reactor Design	3
Humanities or social sciences	3
Semester 7	
CHEME 432, Chemical Engineering Laboratory	4
CHEME 472, Process Control	3
Electives*	6
Humanities or Social Sciences	3
Semester 8	
CHEME 462, Chemical Process Design	4
Humanities or social sciences	3
Electives*	3
Approved elective	3

*The electives in semester seven and eight comprise 6 credits of field approved electives, and
3 credits of CHEME process or systems elective. CHEME process or systems electives include CHEME 564, Design of Chemical Reactors; CHEME 640, Polymeric Materials; CHEME 643, Introduction to Bioprocess Engineering; CHEME 656, Separations Using Membranes or Porous Solids; CHEME 661, Air Pollution Control.

†Applied science electives include BIOMI 290, General Microbiology Lectures; BIOBM 330, 331, 332, and 333, Principles of Biochemistry; CEE 654, Aquatic Chemistry; CHEME 640, Polymeric Materials; FOOD 409, Food Chemistry; MS&E 331, Structure of Materials; MS&E 332, Electrical and Magnetic Properties of Materials; MS&E 441, Microprocessing of Materials; MS&E 449, Introduction to Ceramics; MS&E 452, Properties of Solid Polymers; any A&EP course numbered 333 or above; any CHEM course numbered 301 or above; any PHYS course numbered 300 or above.

Students who entered before fall 1994 should contact the field office for a copy of the curriculum.

Master of Engineering (Chemical) Degree Program

The professional master's degree, M.Eng.(Chemical), is awarded at the end of one year of graduate study with successful completion of 30 credits of required and elective courses in technical fields including engineering, mathematics, chemistry, physics, and business administration. Courses emphasize design and optimization based on the economic factors that affect design alternatives for processes, equipment, and plants. General admission and degree requirements are described in the college's introductory section.

Specific requirements include

1) two courses in advanced chemical engineering fundamentals chosen from CHEME 711, 713, 731, 732, and 751
2) two courses in applied chemical engineering science chosen from CHEME 520, 564, 566, 640, 643, 656, and 661
3) a minimum of 3 credits of a design project, CHEME 565

Dean's certificate programs in Bioengineering, Engineering Management, Energy Engineering, and Manufacturing are available. A program offered jointly with the Food Science Department is also available, leading to both the Master of Engineering and the Master of Professional Studies degrees.

CIVIL AND ENVIRONMENTAL ENGINEERING

A. H. Meyburg, director; J. F. Abel, associate director; F. L. Bennett, S. Billington, J. J. Bisogni, Jr., W. H. Brutsaert, G. G. Deierlein, R. I. Dick, J. M. Gossett, M. D. Grigoriu, D. A. Haith, K. C. Hover, A. R. Ingraffea, F. H. Kulhawy, L. W. Lion, P. L-F. Liu, D. P. Loucks, W. R. Lynn, L. K. Nozick, T. D. O'Rourke, T. Peköz, W. D. Philpot, M. J. Sansalone, R. E. Schuler, C. A. Shoemaker, J. R. Stedinger, H. E. Stewart, M. A. Turnquist, R. N. White

Bachelor of Science Curriculum

The School of Civil and Environmental Engineering offers an accredited undergraduate program in civil engineering and permits students to pursue one of two options leading to the B.S. degree: civil engineering or environmental engineering. Within civil engineering, students may emphasize structural engineering, geotechnical engineering, hydraulics and hydrology, or transportation. The environmental engineering curriculum emphasizes study of environmental engineering, environmental and water resource systems, and hydraulics and hydrology. Sample curricula are available in the school office, 220 Hollister Hall.

Requirements for Admission to the Field:

Students planning to enter the Field Program in Civil and Environmental Engineering are required to complete either ENGRD 202, Mechanics of Solids (for those interested in the Civil option) or ENGRD 219, Mass and Energy Balances (for those interested in the Environmental option) before or during the sophomore year with a grade of C- or better. In addition, the field requires a grade point average of at least 2.0 in engineering and sciences courses and cumulatively for all courses.

Recommended Engineering Distribution Courses:

The recommended engineering distribution course for students planning to enter the environmental engineering option is ENGRD 202, Mechanics of Solids. Students entering the environmental option who have not taken ENGRD 202 will be required to do so as part of the Field Program.

Recommended engineering distribution courses for students planning to enter the civil engineering option are:

ENGRD 261, Introduction to Mechanical Properties of Materials, for students interested in structural engineering or civil engineering materials;

ENGRD 201, Introduction to the Physics and Chemistry of the Earth, for students interested in geotechnical engineering;

ENGRD 221, Thermodynamics, for students interested in fluid mechanics and hydralics/hydrology;

ENGRD 211, Computers and Programming, for students interested in transportation.

Field Program:

These field program requirements will apply to all students in the Classes of 1998 and later.

Environmental Engineering Option

For the Field Program in Environmental Engineering, students must take CHEM 208 in place of PHYS 214. The following nine courses are required in addition to those required for the Common Curriculum:

Courses	*Credits*
ENGRD 241, Engineering Computation*	3
CHEM 357, Introductory Organic Chemistry	3
BIOMI 290, General Microbiology, Lectures	3
CEE 304, Uncertainty Analysis in Engineering†	4
CEE 323, Engineering Economics	3
CEE 331, Fluid Mechanics	4
CEE 341, Introduction to Geotechnical Engineering	4
CEE 351, Environmental Quality Engineering	3
ABEN 475, Environmental System Analysis	3

Additional requirements include a set of two field-approved electives and three design electives from an approved list of courses which is available in the school office. In addition, students must complete one technical communications course from among the courses designated ENGRC or approved Communications courses. If the technical communications course is taken as an expressive art, then students must take an additional approved elective.

Civil Engineering Option

For the Field Program in Civil Engineering, students may elect to substitute CHEM 208 for PHYS 214. The following nine courses are required in addition to those required for the Common Curriculum.

Courses	*Credits*
ENGRD 203, Dynamics	3
ENGRD 241, Engineering Computation*	3
CEE 304, Uncertainty Analysis in Engineering†	4
CEE 323, Engineering Economics and Management	3
CEE 331, Fluid Mechanics	4
CEE 341, Introduction to Geotechnical Engineering	4
CEE 351, Environmental Quality Engineering	3
CEE 361, Introduction to Transportation Engineering	3
CEE 371, Structural Behavior	4

Additional requirements include a set of two field-approved electives and three design electives from an approved list of courses which is available in the school office. In addition, students must complete one technical communications course from among the courses designated ENGRC or approved Communications courses. If the technical communications course is taken as an expressive art, then students must take an additional approved elective from a department or school other than Civil and Environmental Engineering.

*ENGRD 241 can be used to satisfy both the computer application requirement and a field program requirement.

†ENGRD 270 may be accepted (on petition) as a substitute for CEE 304 in the field program, but only if ENGRD 270 is taken before entry into the field, or in some special cases where co-op or study abroad programs necessitate such a substitution.

Civil and Environmental Engineering Honors Program

Eligibility

The Bachelor of Science degree with honors will be granted to students who, in addition to having completed the requirements for a bachelor degree, have satisfactorily completed the honors program in Civil and Environmental Engineering and have been recommended for the degree by the honors committee of the department. An honors program student must enter with and maintain a cumulative GPA ≥ 3.50 and must be eligible for one of the *cum laude* distinctions at the time of graduation. Only students graduating in 1997 or later are eligible (i.e., only those fulfilling the curriculum requirements of the college and school that were adopted in 1994).

Content

A CEE honors program shall consist of at least nine credits beyond the minimum required for graduation in CEE. These nine credits shall be drawn from one or more of the following components:

1. A significant research experience or honors project under the direct supervision of a CEE faculty member using CEE 400: Senior Honors Thesis (1–6 credits per semester). A significant written report or senior honors thesis must be submitted as part of this component.

2. A significant teaching experience under the direct supervision of a faculty member or as part of a regularly recognized course in the College of Engineering (i.e., ENGRG 470: Undergraduate Engineering Teaching or CEE 401: Undergraduate Teaching in CEE (1–3 credits per/ semester).
3. Advanced or graduate courses at the 500-level or above.

The minimum number of credits in any component included in a program should be two. No research, independent study, or teaching for which the student is paid may be counted toward the honors program.

Timing

All interested students must apply no later than the beginning of the first semester of their senior year, but are encouraged to apply as early as the first semester of their junior year. All honors program students must be in the program for at least two semesters prior to graduation.

Procedures

Each applicant to the CEE honors program must have a faculty adviser or faculty mentor to supervise the student's individual program. (This need not be the student's faculty adviser.) The application to the program shall be a letter from the student describing the specific proposed honors program and include the explicit approval of the faculty adviser and the honors adviser. Each program must be approved by the CEE Curriculum Committee, although the committee may delegate approval authority to the Associate Director for all but unusual proposals.

Master of Engineering (Civil) Degree Program

The M.Eng. (Civil) degree program is a 30-credit (usually ten-course) curriculum designed to prepare students for professional practice. There are two options in this program: one in civil and environmental engineering design and one in engineering management. Both options require a broad-based background in an engineering field. Applicants holding an ABET-accredited (or equivalent) undergraduate degree in engineering automatically satisfy this requirement. Those without such preparation will require course work beyond the graduate program's 30-credit minimum to fulfill the engineering preparation requirement. Both options also require one course in professional practice and a two-course project sequence. The project entails synthesis, analysis, decision making, and application of engineering judgment. Normally it is undertaken in cooperation with an outside practitioner, and it includes an intensive, full-time, three-week session between semesters. The general degree requirements and admissions information are described above in the section entitled "Master of Engineering Degree Programs." Each student's program of study is designed individually in consultation with an academic adviser and then submitted to the school's Professional Degree Committee for approval.

For the M.Eng. (Civil) program in civil and environmental engineering design options, the requirements are:

1) Three courses, one in professional engineering practice (CEE 503) and a two-course design project (CEE 501 and 502).
2) Specialization in a major—three to five courses in either environmental engineering, environmental and public systems engineering, geotechnical engineering, hydraulic engineering, remote sensing, structural engineering, or transportation engineering.
3) Two courses in a single related or minor area.
4) Technical electives (up to two courses).

Courses in the minor and electives may consist of graduate or advanced courses in fields related to the major, either inside or outside of the school.

For the M.Eng. (Civil) program in the engineering management option, the requirements are:

1) Five courses: Project Management (CEE 590), Engineering Management Methods (CEE 593 and 594), and the Management Project (CEE 591 and 592).
2) One course in finance, accounting, or engineering economics, as appropriate given a student's background.
3) One course in individual and/or organizational behavior from a recommended list.
4) Three courses from a disciplinary or functional specialization, subject to adviser's approval.

The School of Civil and Environmental Engineering cooperates with the the Johnson Graduate School of Management in two joint programs leading to both Master of Engineering and Master of Business Administration degrees. See the introductory section under College of Engineering.

Applications for the six-year B.S./M.Eng./ M.B.A. program must be submitted at the beginning of the sixth term of study.

COMPUTER SCIENCE

R. L. Constable, chair; K. Birman, C. Cardie, T. Coleman, M. Godfrey, D. Gries, J. Halpern, J. Hartmanis, J. E. Hopcroft, D. Huttenlocher, S. Keshav, J. Kleinberg, D. Kozen, G. Morrisett, K. Pingali, R. A. Rubinfeld, F. B. Schneider, P. Seshadri, B. Smith, E. Tardos, R. Teitelbaum, S. Toueg, C. Van Loan, S. Vavasis, T. vonEicken, R. Zabih

Bachelor of Science Curriculum

The Department of Computer Science is affiliated with both the College of Arts and Sciences and the College of Engineering. Students in either college may major in computer science.

For details, visit our web site at http://www.cs.cornell.edu/Info/Ugrad

The Major

Computer Science majors take courses in algorithms, data structures, logic, programming languages, scientific computing, systems, and theory. Electives in artificial intelligence, computer graphics, computer vision, databases, multimedia, and networks are also possible. Requirements include:

- four semesters of calculus (MATH 111–122–221–222 or 191–192–293–294)
- two semesters of introductory computer programming (COM S 100 and ENGRD 211 or 212)
- a seven-course computer science core (ENGRD 222, COM S 280, 314, 381, 410, 414, and 482)
- two 400+ computer science electives, totaling at least 6 credits
- a computer science project course (COM S 413, 415, 418, 433, 463, or 473)
- a 3+ credit mathematical elective course (OR&IE 270, MATH 300+, T&AM 300+, etc.)
- two 300+ courses (field approved electives) that are technical in nature and total at least six credits
- three courses which are related to one another from a discipline other than computer science. These courses must be numbered 300-level or greater and total at least eleven credits.

The program is broad and rigorous, but it is structured in a way that supports in-depth study of outside areas. Intelligent course selection can set the stage for graduate study and employment in any technical area and any professional area such as business, law, or medicine. With the advisor, the computer science major is expected to put together a coherent program of study that supports career objectives and is true to the aims of liberal education.

Computer Science Honors Program

Eligibility

The Bachelor of Science degree with honors will be granted to students who, in addition to having completed the requirements for a bachelor degree, have:

- maintained a cumulative GPA $\geq$ 3.50
- qualified for *cum laude* honors in the College of Engineering
- completed 8 credit hours of COM S course work at or above the 500-level
- completed 6 credit hours of COM S 490 research with a COM S faculty member, (spread over at least two semesters) obtaining grades of A- or better.

Content

Honors courses may not be used to satisfy the COM S 400+ elective requirement or the COM S project requirement.

Timing

Honors' determinations are made during the senior year. Students wanting to be considered for field honors should notify the Undergraduate Office in the Department of Computer Science via electronic mail at the following address: <ugrad@cs.cornell.edu>. The subject line for this message should read "HONORS TRACK". Related questions may also be addressed to the ugrad e-mail alias, or candidates can call or stop by 303 Upson Hall, 255–0982.

Preparation

Arrangements for doing COM S 490 research should be made directly with faculty members in the department. Students are encouraged to discuss potential contacts with their advisers and/or browse the department's web page at <http://www.cs.cornell.edu> for specific leads on research opportunities.

The Department of Computer Science reserves the right to make changes to the honors program requirements at any time. Generally speaking, all members of the same graduating class in COM S will be subject to the same honors criteria.

Master of Engineering (Computer Science) Degree Program

The one-year program leading to the degree of M.Eng. (Computer Science) admits more than 70 students a year. The "fifth year," as it is sometimes referred to, provides students with the opportunity to more fully establish professional credentials in advanced computing technologies. In recent years, the demand for the "fifth year" has expanded enormously. A strong undergraduate background in computer science or a related field is required. Early admission is available for Cornell seniors who apply in the fall semester. The emphasis of the curriculum can be on programming languages, systems, theory of algorithms, theory of computation, numerical analysis, artificial intelligence, computer graphics/ visualization, multimedia, network systems, or information processing, which includes databases and information organization and retrieval. The required design project could be, for example, the design of a compiler for a large subset of a general-purpose programming language or the solution of a significant engineering problem using computer science techniques.

Cooperative Program with the Johnson Graduate School of Management

Undergraduates majoring in computer science may be interested in a program that can lead, in the course of six years, to B.S., M.Eng. (Computer Science), and M.B.A. degrees. This program, which is sponsored jointly by the College of Engineering and the Johnson Graduate School of Management, enables students to study several subjects required for the M.B.A. degree as part of their undergraduate curriculum. Planning must begin early, however, if all requirements are to be completed on schedule.

For further details and assistance in planning a curriculum, students can consult with their adviser, the undergraduate office in 303 Upson Hall, or the Johnson School directly.

ELECTRICAL ENGINEERING

J. S. Thorp, director; J. M. Ballantyne, T. Berger, A. W. Bojanczyk, G. M. Brown, H.-D. Chiang, R. C. Compton, D. F. Delchamps, L. F. Eastman, D. T. Farley, T. L. Fine, Z. Haas, D. A. Hammer, C. Heegard, S. S. Hemami, C. R. Johnson, Jr., E. Kan, M. C. Kelley, P. M. Kintner, R. Kline, J. P. Krusius, R. L. Liboff, Y.-H. Lo, N. C. MacDonald, P. R. McIsaac, B. Minch, J. A. Nation, T. W. Parks, A. Phillips Jr., C. R. Pollock, C. Pottle, A. P. Reeves, C. E. Seyler, Jr., Y. Y. Shacham, J. R. Shealy, R. N. Sudan, C. L. Tang, N. Tien, R. J. Thomas, H. C. Torng, V. Veeravalli, S. B. Wicker

Bachelor of Science Curriculum

The undergraduate Field Program in Electrical Engineering provides a foundation that reflects the broad scope of this engineering discipline.

Concentrations include computer engineering; control systems; electronic circuit design; information, communication, and decision theory; microwave electronics; plasma physics; power and energy systems; quantum and optical electronics; radio and atmospheric physics; and semiconductor devices and applications.

Electrical Engineering Field Program

Students planning to enter the Field Program in Electrical Engineering must take ENGRD 231 as an engineering distribution course. The fall of the sophomore year is the preferred term for ENGRD 231/ELE E 232 for students without advanced standing in mathematics. Electrical engineering students with an interest in computer engineering are encouraged to take ENGRD 211 as an engineering distribution course prior to entry into the field program. In addition, the field program normally begins in the spring of the sophomore year, as shown below. All of these courses (except ELE E 210) are taught only once each academic year, either spring or fall, as indicated in the course descriptions.

Course	Credits
Field Required Courses	
ELE E 210, Introduction to Electrical Systems	3
ELE E 215, Electrical Systems Laboratory	3
ELE E 232, Practicum in Digital Systems	1
ELE E 301, Electrical Signals and Systems I	3
ELE E 303, Electromagnetic Fields and Waves	3
ELE E 315, Electronic Circuit Design	4
Field Approved Electives (34-credit minimum in the following categories)	
Electrical Engineering Electives†	21 minimum
Electives Outside Field‡ (3 courses)	9 minimum
Total minimum field credits	51

ELE E 310 can be taken in place of ENGRD 270 or T&AM 310 to satisfy the college application of probability and statistics requirement.

†Must include two electrical engineering laboratory courses and at least two courses at the 400-level or above. May not include project courses, such as ELE E 391, 392, 491 or 492.

At least one of the required electrical engineering laboratory courses must be selected from a list including ELE E 416, 425, 430, 453, 457, 475, 476, 488, 490, 530 and 534. The other may be selected from the above list or from among ELE E 423, 426, 433, 439, 451, 452, 471, 472, 524, 526, 536, 539, 554, 558 and 593.

‡Must include one course at the 300-level or above (see *Electrical Engineering Handbook* for details).

All students graduating with a B.S. degree must fulfill the engineering design requirement. To meet this requirement, students must demonstrate that they have completed courses that contain at least 16 credits of engineering design. A table listing the engineering design content of all relevant electrical engineering and computer science courses is available in the electrical engineering undergraduate program office, or on the department web page at http://www.ee.cornell.edu.

Undergraduate specialization is achieved through the various electrical engineering elective courses, as well as other courses in related technical fields within engineering, mathematics, the physical sciences, and the analytical biological sciences. The School of Electrical Engineering offers more than thirty courses that are commonly taken as electives by undergraduates.

Maximum technical course scheduling flexibility in the field program is possible for those students who *do not* complete their 6 credits of College Approved Electives prior to entry into the field program. Accordingly, intended electrical engineering students are advised to consider course selection carefully during their first three terms in engineering.

An electrical engineering honors program also exists for those students who so desire and meet the program entrance requirements. The honors program requires additional courses, a required undergraduate research or design project, or an honors thesis. Details are available in the *Electrical Engineering Handbook* or on the electrical engineering homepage located on the World Wide Web at http://www.ee.cornell.edu.

Students with advanced standing frequently take one or more graduate-level courses prior to graduation and may actually begin the fifth year Master of Electrical Engineering program in their last semester of undergraduate course work so long as 8 or fewer credits remain toward B.S. degree requirements and a 3.0 GPA has been maintained. Admission must be approved in advance of the last semester of undergraduate work.

All students majoring in electrical engineering are expected to meet the following academic standards:

1. Students must achieve a grade-point average of at least 2.3 every semester.
2. No course with a grade of less than C– may be used to satisfy degree requirements in the field program or serve as a prerequisite for a subsequent electrical engineering course.
3. Students must complete satisfactorily ELE E 210, ELE E 215, MATH 294, and PHYS 214 by the end of the first semester in the Field Program of Electrical Engineering, and make adequate progress toward the degree in subsequent semesters.
4. Honors program students must meet the GPA and progress requirements specified in the *Electrical Engineering Handbook* to remain active participants.

Electrical Engineering Honors Program

Eligibility, Entry, and Continuation

A student may apply to enter the EE Honors Program as early as the beginning of the fifth semester and as late as the end of the sixth semester. A student must have a cumulative GPA of at least 3.5 to apply for entry. A student in the honors program whose cumulative GPA falls below 3.5 at the end of any semester will be dropped from the honors program by College of Engineering regulations. There is an additional requirement (see Honors Seminar) for entry into the program after the end of the fifth semester.

Honors Seminar

Any student in the honors program is required to take (or to have taken) an Honors Seminar during his or her junior year. The Honors Seminar is a 2-credit semester-course (offered spring only) consisting of a weekly series of introductory research lectures by Electrical Engineering faculty members. Each Honors Seminar enrollee will be required to write short papers on one of the topics covered in the lecture series. All Electrical Engineering faculty members will be expected to give a lecture or short series of lectures as part of the Honors Seminar at least every two or three years. Students in the honors program and students with a cumulative GPA of at least 3.5 who are considering entering the honors program will receive letter grades for the Honors Seminar. Other students may attend the Honors Seminar for academic credit, but will be graded on an S/U basis for one credit hour.

Honors Project

Any student in the honors program is required to accumulate at least three credit hours from an honors project consisting either of research, teaching, or directed reading. All Honors Projects should place some emphasis on development of communication skills. A 3-credit teaching-oriented honors project would consist of a one-credit seminar on teaching coupled with two credit hours worth of classroom teaching at the level and intensity of Academic Excellence Workshop facilitators. Research- and reading-oriented honors projects, while similar to the senior projects we now offer, should require explicitly a certain amount of writing.

Additional Coursework

Any student in the honors program is required to take at least four credit hours of advanced ELE E coursework that has at least a 300-level prerequisite. These four credit hours are in addition to any credit hours required as part of the ELE E field program.

The program described above would require honors program participants to amass at least nine credit hours over and above the 126 credit hours required for a B.S. degree; thus an honors degree would require a minimum of 135 credit hours.

Master of Engineering (Electrical) Degree Program

The M.Eng.(Electrical) degree program prepares students either for professional work in electrical engineering and closely related areas or for further graduate study in a doctoral program. The M.Eng. degree differs from the Master of Science degree mainly in its emphasis on engineering design and analysis skills rather than basic research.

The program requires 30 credits of advanced technical course work beyond that expected in a typical undergraduate program, including a minimum of four courses in electrical engineering. An electrical engineering design project is also required and may account for 3 to 8 credits of the M.Eng. program. Occasionally, students take part in very extensive projects and may apply for a waiver of the 8-credit maximum and increase the project component to 10 credits. Students with special career goals, such as engineering management, may apply to use up to 8 credits of approved courses that have significant technical content, but are taught in disciplines other than engineering, mathematics, or the physical sciences.

Although admission to the M.Eng.(Electrical) program is highly competitive, all well-qualified students are urged to apply. Further information is available from the Master of Electrical Engineering Program Office in 222 Phillips Hall.

GEOLOGICAL SCIENCES

B. L. Isacks, chair; R. W. Kay, director of undergraduate studies; R. W. Allmendinger, W. Allmon, M. Barazangi, W. A. Bassett, J. M. Bird, L. D. Brown, L. M. Cathles, J. L. Cisne, K. Cook, L. A. Derry, C. H. Greene, T. E. Jordan, S. Mahlburg Kay, F. H. T. Rhodes, W. B. Travers, D. L. Turcotte, W. M. White

Bachelor of Science Curriculum

The Department of Geological Sciences offers two options in its field program, the Geoscience Option and the Science of Earth Systems (SES) Option. The Geoscience Option emphasizes the structure, composition, and evolution of our planet, while the SES Option is more concerned with processes on and near the earth's surface where the interactions of water, life, rock, and air produce our planetary environment.

The Geoscience Option reveals the earth's turbulent history from the formation of our solar system to the plate tectonic cycles that dominate the earth's present behavior. That history is highlighted by the co-evolution of life and the Earth system from the origin of life to the modern inter-glacial phase during which our species has so proliferated. Topics of study also include the fundamental processes responsible for earthquakes, volcanic eruptions, and mountain building. The Geoscience Option prepares students for advanced study in geology, geophysics, geochemistry, and geobiology, and careers in mineral and petroleum exploration or in environmental geology. Alternatively, it is a valuable major for a pre-law or pre-med program or in preparation for a career in K–12 education.

The Science of Earth Systems (SES) Option provides an integrated view of Earth processes critical to the understanding of our environment. This scientific understanding is the primary foundation upon which to determine if, and to what degree, human societies can modify or adapt to future change. The SES Option is for students interested in careers in atmospheric, hydrological and ocean sciences, environmental chemistry (biogeochemistry), and environmental geophysics. The Option enables students in the Engineering College to take part in the multidisciplinary, intercollege program in the Science of Earth Systems (see description in Interdisciplinary Centers, Programs, and Studies). Collaborations with other departments provide breadth and depth to the program.

Geoscience Option

The Geoscience Option stresses a balanced overview of geological sciences with considerable flexibility and a degree of specialization achieved by careful selection of field-approved electives. Students are required to take GEOL 201 (ENGRD 201) as an Engineering Distribution course. For students interested in geobiology or paleontology, BIO G 101/103–102/104 (or BIO G 109–110) are recommended. CHEM 208 may be substituted for PHYS 214.

The Geoscience Option requires the following courses: the introductory outdoor field courses, GEOL 210 and 214, and the five core courses, GEOL 326, 355, 356, 375, and 388. One additional field-required course and at least one field-approved elective must be GEOL 400 through 600-level courses. The core courses may be taken in any reasonable sequence, except that GEOL 355, which is offered in the fall, should be taken before GEOL 356, which is offered in the spring. GEOL 326, 355, 356, and 375 should be taken relatively early in the major program.

In addition, a requirement for an advanced outdoor field experience may be met by completing one of the following 4 credit options: (a) GEOL 491–492 (Undergraduate Research, 2 credits each) with a significant component of field work; (b) GEOL 491 or 492 based on field observations obtained in GEOL 212 (Special January Field Trip, 2 credits) or GEOL 417 (Field Mapping in Argentina, 3 credits) for a combined 4 credit minimum; (c) GEOL 437 (Geophysical Field Methods, 3 credits) plus at least 1 credit of GEOL 491 or 492 using geophysical techniques from GEOL 434; or (d) An approved outdoor field course taught by another college or university (4–credit minimum).

A selection of field-approved electives may provide specializations in geophysics, geochemistry (including petrology and mineralogy), geobiology (paleontology), and geology applied to mineral and petroleum industries, environmental problems, hydrology, and civil engineering. Students intending to specialize in economic geology or pursue careers in the mining industries or mineral exploration should consider including economics courses among their liberal studies distribution courses. Students who want a more general background or who want to remain uncommitted with regard to specialty must choose at least two of their field-approved electives from the same field. The field-approved electives outside the field may be chosen from offerings in other science or engineering fields or the liberal arts, but should be at the 300 level or above. Students may request substitution of GEOL 491 and 492, Undergraduate Research, for a fourth-year field-approved elective but not if it is being used to fulfill the outdoor field requirement.

In addition to course work, students learn by involvement in research projects. Facilities include equipment for processing seismic signals and digital images of the earth's surface, instruments for highly precise isotopic and element analyses, and extensive libraries of earthquake records, satellite images, and exploration seismic records. High-pressure, high-temperature mineral physics research uses the diamond anvil cell and the Cornell High Energy Synchrotron Source (CHESS). Undergraduates have served as field assistants for faculty members and graduate students in

Argentina, British Columbia, the Aleutian Islands, Scotland, Switzerland, Tibet, and Barbados. Undergraduates are encouraged to participate in research activities, frequently as paid assistants.

Science of Earth Systems (SES) Option

The SES Option emphasizes a strong preparation in basic mathematics and sciences and an integrated approach to the study of the earth system including the lithosphere, biosphere, hydrosphere, and atmosphere. The aim is to prepare students for graduate study and careers across the broad spectrum of earth sciences required for successful understanding and management of our planet. The option provides a rigorous base of environmental science that strongly complements Cornell's programs in environmental and agricultural engineering. The SES Option makes an attractive double major with respect to either the Environmental Engineering Option offered by the Department of Civil and Environmental Engineering or the Agricultural Engineering major offered by the Department of Agricultural and Biological Engineering.

Students are required to take a second semester of chemistry, two semesters of biology, and ENGRD 201 (Physics and Chemistry of the Earth) as one of the Engineering Distribution courses. In addition, students take one semester of the two-credit SES Colloquium, which is designed to inform students about the field and to provide a sense of community for SES students and faculty from the several colleges who participate in the SES program. The option requires a set of four core courses, normally taken in the junior or senior years, which provide breadth and integration. An additional set of four intermediate to advanced courses are selected to provide depth and a degree of specialization. These courses permit the student to specialize in atmospheric, hydrologic or ocean sciences, biogeochemistry, environmental geophysics, an approved combination of these areas, or a combination with courses in economics, government, or education in preparation for further study leading to careers in environmental law or management or K-12 education.

The field requirements for the SES Option are summarized as follows. CHEM 208 is required, and may be taken instead of PHYS 214. ENGRD 201 (GEOL 201) is a required engineering distribution course. The Field Program includes BIO G 101/103-102/104 (or BIO G 109-110), the four SES core courses listed below, four additional courses selected with the advisor's approval to provide specialization in one or a combination of the areas covered by SES, and four other field-approved electives. Two of the specialization courses will count as field-required courses, and two as field-approved electives. At least three of the field-approved electives must be non-GEOL courses. The four SES core courses include the following

SES 301 Climate Dynamics (enroll in ASTRO 331 or SCAS 331) Fall, 4 credits;

SES 302 Evolution of the Earth System (enroll in GEOL 302 or SCAS 332) Spring. 4 credits;

SES 321 Biogeochemistry (enroll in GEOL 321 or NTRES 321) Fall. 4 credits;

SES 402 Mechanics in the Earth and Environmental Sciences (enroll in ABEN 385) Spring. 4 credits.

Areas of specialization include at present

- Climate Dynamics, the study of the physical and chemical processes producing Earth's climate system;
- Ocean Sciences, the study of the biological, chemical and physical processes at work in the ocean;
- Hydrological Sciences, the study of the interactions of rock, water, snow and ice on Earth's land surfaces;
- Biogeochemistry, study of element cycling near Earth's surface and how organisms both mediate and benefit from these fluxes;
- Environmental Geophysics, remote sensing of Earth's surface and subsurface applied to the study of the environment, global change, and natural hazards;

As alternatives to these specializations, students may select courses in Civil and Environmental Engineering (Environmental Option) or Agriculture and Biological Engineering to obtain a double Major in SES and in either of these two departments.

In addition to faculty in or associated with the Department of Geological Sciences, faculty currently associated with the SES program include the following: P. Baveye (ABEN); W. Brutsaert (CEE); R. Bryant (SCAS; T. Dawson; (BIOES); P. Gierasch (ASTR); L. Hedin (BIOES); R. Howarth (BIOES, SCAS); M. Kelley (EE); J.-Y. Parlange (ABEN); W. Philpot, (CEE); S. Riha (SCAS); J. Yavitt (NTRES).

Geological Science Honors Program

Eligibility

The Bachelor of Science degree with honors will be granted to students who, in addition to having completed the requirements for a bachelor degree, have satisfactorily completed the honors program in Geological Sciences and have been recommended for the degree by the honors committee of the department. An honors' program student must enter with and maintain a cumulative GPA $\geq$ 3.50 and must be eligible for one of the *cum laude* distinctions at the time of graduation.

Content

In addition to the minimum graduation requirements, a student must

1. take at least 9 credits above the minimum required for graduating and approved by the upperclass adviser;
2. have a written proposal of the honors project accepted by his or her faculty adviser and the director of undergraduate studies;
3. complete an honors thesis involving research (GEOL 491–492, 2 credits each) of breadth, depth, and quality.

Timing

A student interested in completing an honors thesis must, by the beginning of their seventh semester, have a written proposal of his/her honors project accepted by his/her adviser and the director of undergraduate studies.

Procedures

Each application to the Geological Sciences honors program must have a faculty adviser to supervise the honors program. Written approval by the faculty member who will direct the research is required. After the college verifies the student's grade-point average, the student will be officially enrolled in the honors program.

Master of Engineering (Geological Sciences Degree Program)

The Master of Engineering (Geological Sciences) is a one-year professional degree that provides students with intensive training for, and a fast-track into, careers in the burgeoning areas of environmental geoscience and resource exploration. Emphasis is on developing skills with cutting-edge geophysical and computational techniques for remote sensing, subsurface imaging, and modeling of subterranean fluid flow. Extensive facilities are available for GIS, image processing, and seismic and georadar field surveying. Currently, program options include geohydrology and environmental geophysics. Under development is a new option in petroleum exploration, designed for those interested in careers in the resurgent oil exploration industry. Past design projects have included field studies in areas as diverse as the Finger Lakes and the Caribbean.

The program requires 30 credits of postgraduate instruction, at least 10 of which must involve engineering design. Students must also complete a design project, worth between 3 and 12 credits, that has a significant geological component and results in substantial conclusions or recommendations.

General information on admission and degree requirements for the M.Eng. degree programs can be found in the college's introductory section.

MATERIALS SCIENCE AND ENGINEERING

J. M. Blakely, director; D. G. Ast, R. Dieckmann, E. P. Giannelis, D. T. Grubb, C. Y. Li, C. K. Ober, A. L. Ruoff, S. L. Sass, Y. Suzuki, M. O. Thompson

Bachelor of Science Curriculum

Students majoring in materials science and engineering are required to take MS&E 261, Introduction to Mechanical Properties of Materials before affiliating with the field. They are strongly urged to take it as an engineering distribution course during their sophomore year. Students in materials science and engineering must concentrate in a specialization which may cover an area such as materials science, solid state, metallic materials, ceramic materials, polymeric materials, electronic materials, or biomaterials.

Specialization is achieved through the selection of technical electives in the junior and senior years. Optional research involvement courses provide undergraduates with the opportunity to work with faculty members and their research groups on current projects.

The requirements for a Bachelor of Science degree in Materials Science and Engineering are:

1. Completion of common curriculum including humanities and social sciences.
2. Completion of 11 required field courses below:

MS&E 331, Structure of Materials

MS&E 332, Electrical and Magnetic Properties of Materials

MS&E 335, Thermodynamics of Condensed Systems

MS&E 336, Kinetics, Diffusion, and Phase Transformations

MS&E 441, Microprocessing of Materials

MS&E 442, Macroprocessing

MS&E 443/435, Senior Materials Laboratory I or Senior Thesis I

MS&E 444/435, Senior Materials Laboratory II or Senior Thesis II

MS&E 445, Mechanical Properties of Materials

MS&E 447 & 448, Materials Design Concepts I & II

3. Four courses in a technical specialization.
4. Twelve credits of other electives.
5. One of the elective or specialization courses must include substantial chemical synthesis (e.g., MS&E 222, MS&E 414, MS&E 452, CHEM 208 or CHEM 357).

To continue in good standing in the Field of Materials Science and Engineering, students must

1) Maintain an overall 2.0 term average.
2) Maintain an average of 2.3, with no grade below C, in the department's core curriculum.
3) Complete MS&E 261 with a minimum grade of C prior to affiliation.

The department's core curriculum consists of all the required MS&E courses including the MS&E distribution course and the four courses comprising the student's area of specialization.

An attractive and very challenging program combines the materials science and engineering curriculum with that of either electrical engineering or mechanical engineering, leading to a double major. The combination of materials science and engineering with electrical engineering is particularly well suited to students who will eventually be employed in the electronic materials industry. Mechanical engineers knowledgeable in materials science also will be well equipped for technical careers. Curricula leading to the double-major degree must be approved by both of the departments involved and students are urged to plan such curricula as early as possible.

Material Science and Engineering Honors Program

Eligibility

The Bachelor of Science degree with honors will be granted to students who, in addition to having completed the requirements for a bachelor degree, have satisfactorily completed the honors program in Materials Science and Engineering and have been recommended for the degree by the honors committee of the department. An honors program student must enter with and maintain a cumulative GPA $\geq$ 3.50 and must be eligible for one of the *cum laude* distinctions at the time of graduation.

Content

The requirements for an honors degree in Materials Science and Engineering are:

1. Students must take at least nine credits above the minimum required for graduation in Materials Science and Engineering, so that the minimum number of credits for an honors degree is 135. These additional courses must be technical in nature, i.e., in engineering, mathematics, chemistry, and physics at the 400- and graduate-level, with selected courses at the 300-level, which must be approved by the upperclass advisers.
2. A senior honors thesis (eight credits) with a grade of at least an A.

Note: Undergraduates typically enter the Honors program at the beginning of their Senior year (seventh semester), so that they must have a cumulative GPA equal to or greater than 3.50 at that point.

Timing

All interested students must complete a written application no later than the end of the third week of the first semester of their senior year, but are encouraged to make arrangements with a faculty member to work on a senior honors thesis during the second semester of their junior year. A student must be in the program for at least two semesters before graduation.

Procedures

Each application to the Materials Science and Engineering honors program must have a faculty adviser to supervise the honors program. A written approval of the faculty member who will direct the research is required. After the student's grade-point average is verified, the student will be officially enrolled in the honors program.

Master of Engineering (Materials) Degree Program

Students who have completed a four-year undergraduate program in engineering or the physical sciences can be considered for admission into the M.Eng.(Materials) program. This program consists of 30 credits, including course work and a master's design project. The project, which requires individual effort and initiative, is carried out under the supervision of a faculty member. Twelve credits are devoted to the project, which is normally experimental in nature, although computational or theoretical projects are also possible.

Courses for the additional 18 credits are selected from the graduate-level classes in materials science and engineering and from other related engineering fields approved by the faculty. Typically half of the courses are from MS&E. One 3-credit technical elective must include advanced mathematics (modeling, computer application, or computer modeling), beyond the MS&E undergraduate requirements.

MECHANICAL AND AEROSPACE ENGINEERING

D. A. Caughey, director; P. L. Auer, C. T. Avedisian, D. L. Bartel, G. Berkooz, J. F. Booker, I. D. Boyd, P. R. Dawson, P. C. T. deBoer, R. D'Andrea, E. M. Fisher, A. R. George, F. C. Gouldin, S. Kannapan, S. Leibovich, M. Y. Louge, J. L. Lumley, M. P. Miller, F. C. Moon, F. K. Moore, R. M. Phelan, S. B. Pope, M. L. Psiaki, E. L. Resler, Jr., S.-f. Shen, D. L. Taylor, K. E. Torrance, M. C. H. van der Meulen, H. B. Voelcker, K. K. Wang, Z. Warhaft, C. H. K. Williamson, N. Zabaras

Members of the faculty of the graduate Fields of Aerospace Engineering and Mechanical Engineering are listed in the *Announcement of the Graduate School.*

Bachelor of Science Curriculum in Mechanical Engineering

The upperclass Field Program in Mechanical Engineering is designed to provide a broad background in the fundamentals of this discipline as well as to offer an introduction to the many professional and technical areas with which mechanical engineers are concerned. The program covers both major streams of the field of mechanical engineering.

Mechanical systems, design, and materials processing is concerned with the design, analysis, testing, and manufacture of machinery, vehicles, devices, and systems. Particular areas of concentration are mechanical design and analysis, vehicle engineering, biomechanics, and materials processing and precision engineering. Other topics covered are computer-aided design, vibrations, control systems, and dynamics.

Engineering of fluids, energy, and heat-transfer systems is concerned with the efficient conversion of energy in electric power generation and aerospace and surface transportation, the environmental impact of engineering activity (including pollutants and noise), and the experimental and theoretical aspects of fluid flow, heat transfer, thermodynamics, and combustion. Specific areas of concentration include aerospace engineering; heat, energy, and power engineering; and thermo-fluid sciences.

The undergraduate program is a coordinated sequence of courses beginning in the sophomore year. During the fall term sophomore students who plan to enter the Mechanical Engineering Program take ENGRD 202 (also T&AM 202) as an engineering distribution course. They also are encouraged to take ENGRD 221 (also M&AE 221), which is a field requirement that may simultaneously satisfy Common Curriculum requirements as an engineering distribution course. Occasionally because of study abroad or requirements for second majors or pre-med, students cannot complete all of the required sophomore courses on schedule. In such cases students should delay ENGRD 221 until the first semester of the junior year. The Sibley School is supportive of students with unusual requirements, but any delays or substitutions must be discussed with and receive approval from the student's adviser.

The requirements for the degree of Bachelor of Science in Mechanical Engineering are as follows:

1. Completion of the Common Curriculum. During the upperclass years this will typically mean earning credit for five humanities or social science courses.
2. Completion of the field requirements, which consist of eleven required courses (beyond ENGRD 202 already mentioned), and five elective courses (24 credits).

The eleven required courses are:

M&AE 212, Mechanical Properties and Processing of Engineering Materials

M&AE 221, Thermodynamics

M&AE 225, Mechanical Design and Synthesis

T&AM 203, Dynamics

ELE E 210, Introduction to Electrical Systems

M&AE 323, Introductory Fluid Mechanics

M&AE 324, Heat Transfer

M&AE 325, Mechanical Design and Analysis

M&AE 326, System Dynamics

M&AE 427, Fluids/Heat Transfer Laboratory

M&AE 428, Engineering Design

Electives

Students should use the flexibility provided by the field approved electives, approved electives, and humanities/social sciences electives to develop a program to meet their specific goals.

Field Approved Electives

The upper-level program includes five field approved electives. Using these five courses, the student must satisfy the following requirements.

At least three of the courses must be upper-level (300+) M&AE courses. Of these three, two must satisfy a concentration chosen by the student.

Typically these are two courses chosen from an appropriate subset of the school's upper-class offering.

However, students can petition for approval of two related courses to form a custom concentration.

The standard concentrations are

Fluids/Aerospace Engineering, M&AE 305, 306, 423, 506, 507

Thermo-Fluids M&AE 423, 449, 506

Materials Processing M&AE 412, 514

Mechanical Systems M&AE 389, 465, 467, 469, 478, 489

Vehicle Engineering M&AE 386, 449, 486, 506, 507

Of the three upper-level M&AE courses, one must be an approved design elective. The design offerings may change from year to year

Typically this list includes M&AE 401, 464, 486, and 489.

Note that the design elective must be taken during the senior year. Note that a single course may satisfy both the design and concentration requirements, in which case the third course could be any upper level M&AE course.

One of the courses must be an approved upper-level mathematics course taken after MATH 294. The course must include some material on statistics. Currently, the approved courses are T&AM 310 and OR&IE 270.

One of the field approved electives can be viewed as a technical elective and may be any course at an appropriate level, chosen from engineering, mathematics, or science (physics, chemistry, or biological sciences). Appropriate level is interpreted as being at a level beyond the required courses of the college curriculum. Note that courses in economics, business, and organizations are not accepted. Advisers may approve such courses as approved electives.

Approved Electives

To maximize flexibility (i.e., the option for study abroad, COOP, internships, pre-med, and flexibility during the upper-class years), the Sibley School faculty recommends that students delay use of approved electives until after term three. The faculty encourages students to consider the following as possible approved electives:

any engineering distribution course

courses stressing oral or written communications

courses stressing the history of technology

rigorous courses in the physical sciences (physics, biology, chemistry)

courses in informational science (mathematics, computer science)

courses in methodologies (modeling, problem solving, synthesis, design)

courses in technology (equipment, machinery, instruments, devices, processes)

courses in business enterprise operations (economics, financial, legal, etc.)

courses in organizational behavior

courses in cognitive sciences.

Recommendation on Humanities/Social Sciences Electives

Students are encouraged to build a program that includes studies in

history of technology

societal impacts of technology

history

foreign languages

ethics

communications

political science

aesthetics

economics

architecture

An additional graduation requirement of the field program is proof of elementary competence in technical drawing. The demonstration of competence is expected before completion of M&AE 325, Mechanical Design and Analysis. This proof may be given in a number of ways, including satisfactory completion of

a. a technical drawing course in high school or in a community college,

b. ENGRG 102, Drawing and Engineering Design,

c. another technical drawing course at Cornell, or

d. a departmental examination.

The computer applications requirement of the Common Curriculum may be satisfied by several courses, including M&AE 389 or 489.

The writing requirement of the Common Curriculum is satisfied by M&AE 427.

Introduction to Electrical Systems (ELE E 210) may be replaced or supplemented by Electronic Circuits (PHYS 360).

A limited set of third-year courses is offered each summer under the auspices of the Engineering Cooperative Program.

Applicability: The curriculum requirements described above apply to the Class of '98 and beyond. Graduates of the Class of '97 may choose to complete their studies under the previous requirements or those described above. Generally the Sibley School expects the Classes of '96 and '97 to use the requirements described above. More detailed materials describing the Mechanical Engineering Program can be obtained from the Sibley School of Mechanical and Aerospace Engineering, Upson Hall.

Preparation in Aerospace Engineering

Although there is no separate undergraduate program in aerospace engineering, students may prepare for a career in this area by majoring in mechanical engineering and taking courses from the aerospace engineering concentration such as M&AE 305, 306, 506, and 507. Students may prepare for the graduate program in aerospace engineering by majoring in mechanical engineering, in other appropriate engineering specialties such as electrical engineering or engineering physics, or in the physical sciences. Other subjects recommended as preparation for graduate study include thermodynamics, fluid mechanics, applied mathematics, chemistry, and physics.

Master of Engineering (Aerospace) Degree Program

The M.Eng. (Aerospace) degree program provides a one-year course of study for those who wish to develop a high level of competence in engineering science, current technology, and engineering design.

The program is designed to be flexible so that candidates may concentrate on any of a variety of specialty areas. These include aerodynamics, acoustics and noise, turbulent flows, rarefied and non-equilibrium flows, combustion, dynamics and control, CFD, etc.

A coordinated program of courses for the entire year is agreed upon by the student and the faculty adviser. This proposed program, together with a statement of purpose, is submitted for approval to the M&AE Master of Engineering Committee during the first week of class; any subsequent changes must also be approved by the committee. An individual student's curriculum includes a 4- to 8-credit design course, a major concentration consisting of a minimum of 12 credits, and sufficient technical electives to meet the total degree requirement of 30 credits (of which at least 28 credits must have letter grades).

The design projects may arise from individual faculty and student interests or from collaboration with industry. All projects must have an aerospace engineering design focus and have the close supervision of a faculty member.

The courses that constitute the major concentration must be graduate-level courses in aerospace engineering. In general, all courses must be beyond the level of those required in an undergraduate engineering program; credit may be granted for an upper-level undergraduate course if the student has done little or no previous work in that subject area, but such courses must have the special approval of the M&AE Master of Engineering Committee.

The technical electives may be courses of appropriate level in mathematics, physics, chemistry, or engineering; a maximum of 6 credits may be taken in areas other than these if the courses are part of a well-defined program leading to specific professional objectives. It is expected that all students will use technical electives to develop proficiency in mathematics beyond the minimum required of Cornell engineering undergraduates if they have not already done so before entering the program. Courses in advanced engineering mathematics or statistics are particularly recommended.

Students should check with the M&AE graduate field office (104 Upson Hall) for additional degree requirements.

Master of Engineering (Mechanical) Degree Program

The M.Eng. (Mechanical) degree program provides a one-year course of study for those who wish to develop a high level of competence in engineering science, current technology, and engineering design.

The program is designed to be flexible so that candidates may concentrate on any of a variety of specialty areas. These include biomechanical engineering, combustion, energy and power systems, fluid mechanics, heat transfer, materials and manufacturing engineering, mechanical systems and design, CFD, CAE, CAD, CAM, etc.

A coordinated program of courses for the entire year is agreed upon by the student and the faculty adviser. This proposed program, together with a statement of purpose, is submitted for approval to the M&AE Master of Engineering Committee during the first week of class; any subsequent changes must also be approved by the committee. An individual student's curriculum includes a 4- to 8-credit design course, a major concentration consisting of a minimum of 12 credits, and sufficient technical electives to meet the total degree requirement of 30 credits (of which at least 28 credits must have letter grades).

The design projects may arise from individual faculty and student interests or from collaboration with industry. All projects must have a mechanical engineering design focus and have the close supervision of a faculty member.

The courses that constitute the major concentration must be graduate-level courses in mechanical and aerospace engineering or a closely related field such as theoretical and applied mechanics. In general, all courses must be beyond the level of those required in an undergraduate engineering program; credit may be granted for an upper-level undergraduate course if the student has done little or no previous work in that subject area, but such courses must have the special approval of the M&AE Master of Engineering Committee.

The technical electives may be courses of appropriate level in mathematics, physics, chemistry, or engineering; a maximum of 6 credits may be taken in areas other than these if the courses are part of a well-defined program leading to specific professional objectives. It is expected that all students will use technical electives to develop proficiency in mathematics beyond the minimum required of Cornell engineering undergraduates if they have not already done so before entering the program. Courses in advanced engineering mathematics or statistics are particularly recommended.

Students should check with the M&AE graduate field office (104 Upson Hall) for additional degree requirements.

Students enrolled in the M.Eng. (Mechanical) degree program may take courses that also satisfy the requirements of the Manufacturing, Energy, or Electronic Packaging option programs leading to special dean's certificates in those areas.

NUCLEAR SCIENCE AND ENGINEERING

Faculty members in the graduate Field of Nuclear Science and Engineering who are most directly concerned with the curriculum include K. B. Cady, D. D. Clark, H. H. Fleischmann, D. A. Hammer, V. O. Kostroun, and S. C. McGuire

Undergraduate Study

Although there is no special undergraduate field program in nuclear science and engineering, students who intend to enter graduate programs in this area are encouraged to begin specialization at the undergraduate level. This may be done by choice of electives within regular field programs (such as those in engineering physics, materials science and engineering, and civil, chemical, electrical, or mechanical engineering) or within the College Program.

Master of Engineering (Nuclear) Degree Program

The two-term curriculum leading to the M.Eng.(Nuclear) degree is intended primarily for individuals who want a terminal professional degree, but it may also serve as preparation for doctoral study in nuclear science and engineering. The course of study covers the basic principles of nuclear reactor systems with a major emphasis on reactor safety and radiation protection and control. The special facilities of the Ward Center for Nuclear Sciences are described in the *Announcement of the Graduate School*.

The interdisciplinary nature of nuclear engineering allows students to enter from a variety of undergraduate specializations. The recommended background is (1) an accredited baccalaureate degree in engineering, physics, or applied science; (2) physics, including atomic and nuclear physics; (3) mathematics, including advanced calculus; and (4) thermodynamics. Students should see that they fulfill these requirements before beginning the program. In some cases, deficiencies in preparatory work may be made up by informal study during the preceding summer. General admission and degree requirements are described in the college's introductory section.

The following courses are included in the 30-credit program:

Fall term

NS&E 509, Nuclear Physics for Applications

A&EP 612, Nuclear Reactor Theory

A&EP 633, Nuclear Engineering

Technical elective

Spring term

A&EP 651, Nuclear Measurements Laboratory

NS&E 545, Energy Seminar

Technical elective

Engineering design project

Mathematics or physics elective

Engineering electives should be in a subject area relevant to nuclear engineering, such as energy conversion, radiation protection and control, feedback control systems, magnetohydrodynamics, controlled thermonuclear fusion, and environmental engineering. The list below gives typical electives.

M&AE 651, Advanced Heat Transfer

ELE E 581, Introduction to Plasma Physics

ELE E 582, Basic Plasma Physics

ELE E 471, Feedback Control Systems

ELE E 472, Digital Control Systems

A&EP 661, Microcharacterization

NS&E 484, Introduction to Controlled Fusion: Principles and Technology

NS&E 621, Radiation Effects In Microelectronics

MS&E 459, Physics of Modern Materials Analysis

Program for Applications of Nuclear Analytical Methods (PANAM)

This new program was initiated in 1993–94. It provides for specialization by Ph.D. candidates with either a major or a minor in NS&E. For those with majors in non-nuclear fields who expect to use nuclear analytical methods in their research, the sequence NS&E 509–551–590 forms a suitable minor in NS&E. The laboratory course 551 has been offered since spring 1989. The lecture course 509, offered for the first time in 1993, covers nuclear physics without requiring quantum mechanics as a prerequisite. For NS&E majors, PANAM offers the opportunity to extend and develop new nuclear-analytical methods, for example, uses of cold neutrons and neutron-depth profiling with conversion electrons. They would normally follow the M.Eng. program in the first year, continue with advanced courses in the second year (including a full quantum-mechanical treatment of nuclear physics), and begin, as early as possible, independent projects as precursors to thesis research.

OPERATIONS RESEARCH AND INDUSTRIAL ENGINEERING

R. G. Bland, director; J. Renegar, D. Ruppert, associate directors; L. J. Billera, D. C. Heath, P. L. Jackson, W. L. Maxwell, J. A. Muckstadt, N. Prabhu, S. I. Resnick, R. Roundy, G. Samorodnitsky, L. W. Schruben, D. B. Shmoys, E. Slate, G. Swindle, É. Tardos, M. J. Todd, L. E. Trotter, Jr., B. W. Turnbull, L. I. Weiss

Bachelor of Science Curriculum in Operations Research and Industrial Engineering

The program is designed to provide a broad and basic education in the techniques and modeling concepts needed to analyze and design complex systems and to provide an introduction to the technical and professional areas with which operations researchers and industrial engineers are concerned. Exceptional students interested in pursuing graduate studies are encouraged to speak with their faculty advisers concerning an accelerated program of study.

A student who intends to enter the Field Program in Operations Research and Industrial Engineering should plan to take Basic Engineering Probability and Statistics (ENGRD 270) after completing MATH 192. Early consultation with a faculty member of the school or with the associate director for undergraduate studies can be helpful in making appropriate choices. The required courses for the OR&IE field program and the typical terms in which they are taken are as follows:

Term 2, 3 or 4	*Credits*
ENGRD 211, Computers & Programming or ENGRD 212, Structure and Interpretation of Computer Programs	3
Term 5	
OR&IE 320, Optimization I	4
OR&IE 350, Financial and Managerial Accounting	4
OR&IE 360, Engineering Probability and Statistics II	4
A course in humanities and social sciences	3
Field-approved elective	3
Term 6	
OR&IE 310, Industrial Systems Analysis	4
OR&IE 321, Optimization II	4
OR&IE 361, Introductory Engineering Stochastic Processes I	4
Behavioral science†	3
Course in humanities and social sciences	3

†The behavioral science requirement can be satisfied by any one of several courses, including the Johnson Graduate School of Management (JGSM) course, NCC 554 (offered only in the fall), which is recommended for those contemplating the pursuit of a graduate business degree, and ILROB 170, 171, and 320. The adviser must approve the selection in all cases.

The basic senior-year program, from which individualized programs are developed, consists of the following courses:

	Minimum credits
OR&IE 580, Design and Analysis of Simulated Systems	4
Three upperclass OR&IE electives as described below	9
Two field-approved electives (at least 3 credits must be outside OR&IE)	6
Two courses in humanities and social sciences	6
Two approved electives	6

Available OR&IE electives are as follows:

Manufacturing and distribution systems: OR&IE 416, 417, 451, 524, 525, and 562 and JGSM NBA 641

Optimization methods: OR&IE 431, 432, and 435

Applied probability and statistics: OR&IE 462, 475 (2 credits), 476 (2 credits), 561, 563, 575 (2 credits), and 577

Scholastic requirements for the field are a passing grade in every course, a grade of C- or better in ENGRD 211 and 270, OR&IE 310, 321, 350, 360, 361 (applies to Class of 1999 and later), an overall average of at least 2.0 for each term the student is enrolled in the school, an average of 2.0 or better for OR&IE field courses, and satisfactory progress toward the completion of the degree requirements. The student's performance is reviewed at the conclusion of each term.

Operations Research and Industrial Engineering Honors Program

Eligibility

The Bachelor of Science degree with honors will be granted to students who, in addition to having completed the requirements for a bachelor degree, have satisfactorily completed the honors program in Operations Research and Industrial Engineering and have been recommended for the degree by the honors committee of the department. An honors program student must enter with and maintain a cumulative GPA$\geq$ 3.50 and must be eligible for one of the *cum laude* distinctions at the time of graduation.

Content

An OR&IE honors program shall consist of at least nine credits beyond the minimum required for graduation in OR&IE, so that no part of the honors program can also be used to satisfy graduation requirements. The nine credits shall be from one or more of the following with at least four hours in the first category:

1. Advanced courses in OR&IE at the 500-level or above.
2. A significant research experience or honors project under the direct supervision of an OR&IE faculty member using OR&IE 499: OR&IE Project. A significant written report must be submitted as part of this component.
3. A significant teaching experience under the direct supervision of a faculty member in OR&IE using OR&IE 490: Teaching in OR&IE, or ENGRG 470: Undergraduate Engineering Teaching.

Timing

All interested students must complete a written application no later than the end of the third week of the first semester of their senior year, but are encouraged to make arrangements with a faculty member during the first semester of their junior year. A student must be in the program for at least two semesters before graduation.

Procedures

Each application to the OR&IE honors program must have a faculty adviser to supervise the honors program. The honors adviser need not be the students faculty adviser. The application to the program shall be a letter from the student describing the specific proposed honors program and including the explicit approval of the honors adviser. Each program must be approved by the associate director, and any changes to the student's program must also be approved by the associate director of undergraduate studies.

Master of Engineering (OR&IE) Degree Program

This one-year professional degree program stresses applications of operations research and industrial engineering and requires completion of a project. The course work centers on additional study of analytical techniques, with particular emphasis on engineering applications, especially in the design or improvement of man-machine systems, information systems and control systems, and in the financial world.

General admission and degree requirements are described in the introductory "Degree Programs" section. The M.Eng.(OR&IE) program is integrated with the undergraduate Field Program in Operations Research and Industrial Engineering. We also welcome applications from Cornell undergraduates in many other majors, or from qualified non-Cornellians. To ensure completion of the program in one calendar year, the entering student should have completed courses in statistics and in computer programming (Pascal or C). Students interested in the Manufacturing Option should obtain further information from the Center for Manufacturing Enterprise, 103 Frank H. T. Rhodes Hall, 607–255–7757. Students interested in the Financial Engineering Option should contact the Financial Engineering Option Office in 201 Frank H. T. Rhodes Hall, 607–255–9128. Information concerning industrial internships can be obtained from the Master of Engineering Program Office, 148 Olin Hall.

I. *For matriculants with preparation comparable to that provided by the undergraduate Field Program in Operations Research and Industrial Engineering:*

Fall term	*Credits*
OR&IE 516, Case Studies	1
OR&IE 893, Applied OR&IE Colloquium	1
M.Eng. Project	1
Technical electives	12
Spring term	
OR&IE 894, Applied OR&IE Colloquium	1
M.Eng. Project	minimum of 4
Technical electives	9

At least 12 credit hours of the electives specified above must be chosen from the list of courses offered by the School of Operations Research and Industrial Engineering. Other restrictions apply. A minimum of 30 credits must be taken to complete the program.

II. For matriculants from other fields who minimally fulfill the prerequisite requirements (students who have the equivalent of OR&IE 520, 523, and 560 will take other technical electives in their place):

Fall term	*Credits*
OR&IE 560, Engineering Probability and Statistics II	4
OR&IE 520, Optimization I	4
OR&IE 522, Topics in Linear Optimization	1
OR&IE 516, Case Studies	1
OR&IE 580, Design and Analysis of Simulated Systems	4
OR&IE 893, Applied OR&IE Colloquium	1
M. Eng. Project	1
Spring term	
OR&IE 523, Introduction to Stochastic Processes I	4
OR&IE 894, Applied OR&IE Colloquium	1
M.Eng. Project	minimum of 4
Technical electives	6

A minimum of 30 credit hours are required to complete this program. Additional program requirements exist and are described in the Master of Engineering Handbook, which is available in Room 201, Frank H. T. Rhodes Hall.

The project requirement can be filled in a variety of ways. Common elements in all project experiences include working as part of a group of three to five students on an engineering design problem, meeting with a faculty member on a regular basis, and oral and written presentation of the results obtained. Most projects address problems that actually exist in manufacturing firms, financial firms, hospitals and other service industries.

Cooperative Program with the Johnson Graduate School of Management

Undergraduates majoring in operations research and industrial engineering may be interested in a cooperative program at Cornell that leads to both Master of Engineering and Master of Business Administration (M.B.A.) degrees. With appropriate curriculum planning such a combined B.S./M.Eng./M.B.A. program can be completed in six years.

An advantage for OR&IE majors is that they study, as part of their undergraduate curriculum, several subjects that are required for the M.B.A. degree. (This is because modern management is concerned with the operation of production and service systems, and much of the analytical methodology required to deal with operating decisions is the same as that used by systems engineers in designing these systems.) An early start on meeting the business-degree requirements permits students accepted into the cooperative program to earn both the M.Eng.(OR&IE) and M.B.A. degrees in two years rather than the three years such a program would normally take.

The details of planning courses for this program should be discussed with the admissions office of the Johnson Graduate School of Management.

In accordance with this program the candidate would qualify for the B.S. degree at the end of four years, the M.Eng.(OR&IE) degree at the end of five years, and the M.B.A. degree at the end of six years.

Further details and application forms may be obtained at the office of the School of Operations Research and Industrial Engineering, Frank H. T. Rhodes Hall, and at the admissions office of the Johnson Graduate School of Management.

In addition, there are two other programs that combine an M.Eng. (OR&IE) degree and an MBA degree from Cornell. The Twelve-Month MBA Program allows students to obtain both degrees in two academic years plus the intervening summer. The combined M.Eng.-MBA Program allows students to obtain both degrees in a total of five semesters.

STATISTICAL SCIENCE DEPARTMENT

The university-wide Department of Statistical Science coordinates undergraduate and graduate study in statistics and probability. A list of suitable courses can be found in the Interdisciplinary Centers, Programs, and Studies section at the front of this catalog.

THEORETICAL AND APPLIED MECHANICS

J. T. Jenkins, chair; J. A. Burns, K. B. Cady, H. D. Conway, J. M. Guckenheimer, E. W. Hart, T. J. Healey, C. Y. Hui, R. H. Lance, S. Mukherjee, Y. H. Pao, S. L. Phoenix, R. H. Rand, P. Rosakis, A. L. Ruina, W. H. Sachse, S. Strogatz, A. Zehnder

Undergraduate Study

The Department of Theoretical and Applied Mechanics is responsible for courses in engineering mechanics and engineering mathematics, some of which are part of the Common Curriculum.

College Program in Engineering Science

A student may enroll in the College Program in Engineering Science, which is sponsored by the Department of Theoretical and Applied Mechanics. The College Program is described in the section on undergraduate study in the College of Engineering.

Master of Engineering (Engineering Mechanics) Degree Program

Composite materials designed to meet specific requirements of weight, strength, and rigidity are used increasingly in the manufacture of everyday structures and components. The Master of Engineering (Engineering Mechanics) degree program focuses on the mechanical behavior of advanced composite materials and structures and prepares students to play a role in the development of this new technology. Students from diverse engineering backgrounds, such as mechanics, structures, and materials, as well as aerospace and biomedical engineering, can normally complete the requirements for the professional Master of Engineering degree in one year.

The degree program requires satisfactory completion of 30 credits of course work, including 12 credits of courses that involve analysis, computation, design, or laboratory experience. Of these 12 credits, at least 6 must be earned in T&AM. Up to 10 credits will be awarded for an individual project involving composites. The balance of the required credits may be earned in elective courses chosen from those in the course listing below or others approved by the student's adviser.

The Department of Theoretical and Applied Mechanics has several laboratories equipped for the fabrication and mechanical testing of composite materials and structures. Extensive computing resources are available for numerical computations, design, or other numerical- or simulation-research activities related to composites. The Materials Science Center, the Center for Theory and Simulation in Science and Engineering, and the Computer-Aided Design Instructional Facility provide additional state-of-the-art laboratories and computer resources.

ENGINEERING COURSES

Courses offered in the College of Engineering are listed under the various departments and schools.

Courses are identified with a standard abbreviation followed by a three-digit number.

Engineering Communications	ENGRC
Engineering Distribution	ENGRD
Engineering General Interest	ENGRG
Introduction to Engineering	ENGRI
Agricultural and Biological Engineering	ABEN
Applied and Engineering Physics	A&EP
Chemical Engineering	CHEME
Civil and Environmental Engineering	CEE
Computer Science	COM S
Electrical Engineering	ELE E
Geological Sciences	GEOL
Materials Science and Engineering	MS&E
Mechanical and Aerospace Engineering	M&AE
Nuclear Science and Engineering	NS&E
Operations Research and Industrial Engineering	OR&IE
Theoretical and Applied Mechanics	T&AM

ENGINEERING COMMON COURSES

Engineering Communications Courses

Courses in this category, offered by the Engineering Communications Program, develop writing and oral presentation skills relevant to engineers.

ENGRC 233/433 Topics in Engineering Communications
TBA. 3 credits.
Topics vary as the need and interest arise. Sample topics are: introductory technical communications, graphic presentation of engineering material, desktop publishing, information technologies, advanced problems in engineering communications, technology and the law. Fulfills the college technical writing requirement.

ENGRC 234/434 Independent Study in Engineering Communications
TBA. Variable credits (1–3). Credit and course level (234 or 434) determined by the amount and intellectual level of the work.
Students work closely with a Communications Program instructor to pursue an aspect of professional communications not available through regular course work. Projects may involve writing technical documentation, creating user manuals, analyzing and producing technical graphics, or reading and writing about problems in engineering practice. Interested students should contact the Engineering Communications Program.

ENGRC 301 Writing in Engineering
TBA. 1 credit. Prerequisite: permission of instructor. Can be used to satisfy requirements in expressive arts as a free or approved elective. *This course can only be taken in conjunction with a "writing-intensive" engineering class.*
Some "writing-intensive" engineering classes may require students to enroll in this supplementary course. Instructors from the Engineering Communications Program work with engineering faculty members to prepare students for writing assignments. Intended to strengthen understanding of the course content while enhancing communications skills. May be taken more than once, with different engineering courses.

ENGRC 350 Engineering Communications
Fall, spring, summer. 3 credits. Limited to 20 students per section.
Emphasizes technical and professional writing; also includes oral and visual presentation. Material from real-life engineering situations is analyzed, with case studies and assignments modeled on professional situations. Students learn to adapt language and formats—letters, memoranda, instructions, definitions, proposals, reports—to audiences having different needs and levels of technical expertise. Students also consider organizational and ethical dimensions of the communications they encounter and produce. Taught as a workshop, with ample time for discussion. The goal throughout is clear, well-organized, responsible, and forceful professional communication. Fulfills the college technical writing requirement. Fee will be charged to cover photocopying costs.

ENGRC 435 Communications for Engineering Managers
Fall, spring. 3 credits. Limited to 20 students per section.
Guidance and practice in professional writing through a variety of assignments, including case write-ups on management issues. Emphasizes working effectively in teams (topics include listening skills, team roles, and respectful disagreement) and communicating with a variety of audiences, particularly technical and managerial audiences. The course is taught as a workshop and focuses on oral as well as written communication skills. Fulfills the college technical writing requirement. Lab fee will be charged to cover photocopying costs.

Engineering Distribution Courses

Courses in this category are sophomore-level courses cross-listed with a department. These courses are intended to introduce students to more advanced concepts of engineering and may require pre- or co-requisites.

ENGRD 201 Introduction to the Physics and Chemistry of the Earth (also GEOL 201)
Spring. 3 credits. Prerequisites: MATH 191 and PHYS 112. L. M. Cathles.
Formation of the solar system: accretion and evolution of the earth. The rock cycle: radioactive isotypes and the geological time scale, plate tectonics, rock and minerals, earth dynamics, mantle plumes. The hydrologic cycle: runoff, floods and sedimentation, groundwater flow, contaminant transport. Weathering cycle: chemical cycles, CO_2 (weathering), rock cycle, controls on global temperature (CO_2 or ocean currents), oil and mineral resources.

ENGRD 202 Mechanics of Solids (also T&AM 202)
Fall, spring. 3 credits. Prerequisite: PHYS 112, coregistration in MATH 293 or permission of instructor.
Principles of statics, force systems, and equilibrium; frameworks; mechanics of deformable solids, stress, strain, statically indeterminate problems; mechanical properties of engineering materials; axial force, shearing force, bending moment, plane stress; Mohr's circle; bending and torsion of bars; buckling and plastic behavior.

ENGRD 203 Dynamics (also T&AM 203)
Fall, spring. 3 credits. Prerequisite: T&AM 202, coregistration in MATH 294, or permission of instructor.
Newtonian dynamics of a particle, systems of particles, a rigid body. Kinematics, motion relative to a moving frame. Impulse, momentum, angular momentum, energy. Rigid-body kinematics, angular velocity, moment of momentum, the inertia tensor. Euler equations, the gyroscope.

ENGRD 210 Introduction to Electrical Systems (also ELE E 210)
Fall, spring. 3 credits. Corequisites: MATH 293 and PHYS 213.
Fundamental circuit elements and laws, circuit analysis techniques, and operational amplifiers circuits. Response of linear systems, with an introduction to complex frequency and phasors, forced response, average power, transfer function, and the frequency spectrum.

ENGRD 211 Computers and Programming (also COM S 211)
Fall, spring, summer. 3 credits. Credit will not be granted for both ENGRD/COM S 211 and 212. Prerequisite: COM S 100 or equivalent programming experience.
Intermediate programming in a high-level language and introduction to computer science. Topics include program structure and organization, modules (classes), program development, proofs of program correctness, recursion, data structures and types (lists, stacks, queues, trees), object-oriented and functional programming, and analysis of algorithms. Java is the principal programming language.

ENGRD 212 Structure and Interpretation of Computer Programs (also COM S 212)
Fall, spring. 4 credits. Credit will not be granted for both ENGRD/COM S 211 and 212. Prerequisite: COM S 100 or equivalent programming experience.
A challenging introduction to programming languages and computer science that emphasizes alternative modes of algorithmic expression. Topics include recursive and higher-order procedures, performance analysis of algorithms, proofs of program correctness, probabilistic algorithms, symbolic hierarchical data, abstract data types, polymorphic functions, object-oriented programming, infinite data types, simulation, and the interpretation of programs.

ENGRD/COM S 212 covers a wide range of topics in computer science and programming using advanced functional and object-oriented programming languages. ENGRD/COM S 211 focuses on strengthening programming skills in a more conventional programming language (Java), while still introducing important topics in computing. Either course is a suitable prerequisite for further study in the field. Appropriate transfers between ENGRD/COM S 211 and 212 (in either direction) are encouraged during the first few weeks of the semester.

ENGRD 219 Mass and Energy Balances (also CHEME 219)
Fall. 3 credits. Co-requisite: physical or organic chemistry or permission of instructor. P. Clancy.
Engineering problems involving material and energy balances. Batch and continuous reactive systems in the steady and unsteady states. Introduction to phase equilibria for multicomponent systems.

ENGRD 221 Thermodynamics (also M&AE 221)
Fall, spring. 3 credits. Prerequisites: MATH 192 and PHYS 112.
The definitions, concepts, and laws of thermodynamics. Applications to ideal and real gases, vapor and gas power systems, refrigeration and heat pump systems. Thermodynamics relations for simple, compressible substances. Gaseous reactions.

ENGRD 222 Introduction to Scientific Computation (also COM S 222)
Spring, summer. 3 credits. Prerequisites: COM S 100 and (MATH 222 or MATH 294).
An introduction to elementary numerical analysis and scientific computation. Topics include interpolation, quadrature, linear and nonlinear equation solving, least-squares fitting, and ordinary differential equations. The Matlab computing environment is used. Vectorization, efficiency, reliability, and

stability are stressed. Special lectures on parallel computation.

ENGRD 231 Introduction to Digital Systems

Fall, spring. 3 credits. Prerequisite: COM S 100.

An introduction to basic principles, design techniques, and methodology for communication, computer, and information systems, which process digital data streams. Includes Boolean algebra, integrated circuit components, switching circuits, and systems which provide computation, data, voice, and video service.

ENGRD 241 Engineering Computation (also CEE 241)

Spring. 3 credits. Prerequisites: COM S 100 and MATH 293. Co-requisite: MATH 294. J. F. Abel.

This course introduces the discipline of numerical methods while developing programming and graphics proficiency with MATLAB and spreadsheets. Numerical analysis topics considered are accuracy, precision, Taylor-series approximations, truncation and round-off errors, condition numbers, operation counts, convergence, and stability. Included are numerical methods for solving engineering problems that entail roots of functions, simultaneous linear equations, regression, interpolation, numerical differentiation and integration, and ordinary differential equations. The context and solution of partial differential equations are broached. Applications are drawn from different areas of engineering.

ENGRD 250 Engineering Applications in Biological Systems (also ABEN 250)

Fall. 3 credits. Prerequisite: enrollment in an engineering curriculum. Recommended for the sophomore year. B. A. Ahner.

Case studies of engineering problems in agricultural and biological systems, including animal and crop production, environmental problems, energy, biomedicine, and food engineering. Emphasis is on the application of mathematics, physics, and the engineering sciences to energy and mass balances in biological systems.

ENGRD 261 Introduction to Mechanical Properties of Materials (also MS&E 261)

Fall. 3 credits. S. L. Sass.

This course examines the relationship of elastic deformation, plastic deformation, and fracture properties to structure and defects on a microscopic scale in metals, ceramics, polymers, and composite materials. Design and processing of materials to achieve high modulus, damping capacity, strength, fracture resistance, creep resistance, or fatigue resistance. Flaw-tolerant design methods using fracture mechanics.

ENGRD 264 Computerized Instrumentation Design (also A&EP 264)

Fall, spring. 3 credits. Prerequisites: Engr 100 or COM S 100. 1 lec, 1 lab. Fall: T. Cool; spring: J. Brock.

This course covers the use of a small computer in an engineering or scientific research laboratory. Various experiments are performed using an IBM-AT style computer (80486) running Windows. The experiments and devices to be investigated include: input and output ports, analog to digital converters (ADC), digital to analog converters (DAC), thermistors, optical sensors, digital temperature control, non-linear least squares curve fitting of experimental data, thermal diffusion, and viscosity of fluids. A second goal of this course is to develop effective written communication skills in the context of science and engineering. A number of rhetorical principles will be presented that can produce clarity in communication without oversimplifying scientific issues. Students will prepare progress reports, technical reports, and formal articles based on the experiments.

ENGRD 270 Basic Engineering Probability and Statistics (also OR&IE 270)

Fall, spring. 3 credits. Pre or co-requisite: MATH 293.

This course should give students a working knowledge of basic probability and statistics and their application to engineering. Computer analysis of data and simulation are emphasized. Topics include random variables, probability distributions, expectation, estimation, testing, experimental design, quality control, and regression.

Courses of General Interest

Courses in this category are of general interest and cover technical, historical, and social issues relevant to the engineering profession. These courses may also include seminar or tutorial type courses.

ENGRG 102 Mechanical Drafting

Fall, spring. 1 credit. Half-term course offered twice each semester. Enrollment limited to thirty-two per half-term. Recommended for students without mechanical drawing experience. S-U grades optional.

Introduction to sketching, drawing, and graphic techniques useful in design, analysis, and presentation of ideas. Computer-aided design is integral to the course-work and final design project.

ENGRG 150 Engineering Seminar

Fall. 1 credit. First-year students only. S-U grades only.

Engineering freshmen meet regularly with their faculty advisors to discuss a range of engineering topics. Discussions may include the engineering curriculum and student programs, what different types of engineers do, the character of engineering careers, active research areas in the college and in engineering in general, and study and examination skills useful for engineering students. Groups may visit campus academic, engineering, and research facilities.

ENGRG 250 Technology in Society (also ELE E 250, S&TS 250, HIST 250)

Fall. 3 credits. Meets humanities distribution requirement.

This course will investigate the history of technology in Europe and the United States from ancient times to the present. Topics include the economic and social aspects of industrialization; the myths of heroic inventors like Morse, Edison, and Ford; the government's regulation of technology, the origins of mass production, and the spread of the automobile and microelectronics cultures in the United States.

ENGRG 298 Inventing the Power and Information Society (also ELE E 298 and S&TS 292)

Spring. 3 credits. Approved for humanities distribution, not as field electives.

Explores the history of electricity in society from the 1830s to the present by considering the technical and social history of telecommunications, the electric-power industry, radio, television, and computers. Emphasis is placed on the changing relationship between science and technology, the economic aspects of innovation, and the social relations of this technology.

ENGRG 323 Engineering Economics and Management (also CEE 323)

Spring. 3 credits. Primarily for juniors and seniors. D. P. Loucks.

Introduction to engineering and business economics and to project management. Intended to give students a working knowledge of money management and how to make economic comparisons of alternative engineering designs or projects. The impact of inflation, taxation, depreciation, financial planning, economic optimization, project scheduling, and legal and regulatory issues are introduced and applied to economic investment and project-management problems.

[ENGRG 356 Women in Engineering Career Planning Seminar

Spring. 1 credit. Limited to 25 students. S–U grades only. Not offered 1997–98.

Covers aspects of transition to the engineering profession and related issues especially of interest to women. Topics include career and life planning, the job-search process, interviewing strategies, juggling career and family, graduate education, sexual harassment and sexism in the workplace, professionalism, and networking. Corporate professionals and Cornell faculty and staff participate in class discussions.]

ENGRG 360 Ethical Issues in Engineering (also S&TS 360)

Spring. 3 credits. A humanities elective for engineering students. Open to sophomores.

A discussion of ethical issues encountered in engineering practice, such as the rights of engineers in corporations, responsibility for actions, whistleblowing, conflicts of interest, and decision making based on cost-benefit analysis. Codes of ethics and ethical theory will be used to sort out conflicts the engineer may feel toward public safety, professional standards, employers, colleagues, and family. Students will present a case study to the class.

ENGRG 461 Entrepreneurship For Engineers

Fall. 3 credits.

See M&AE 461 for course description.

ENGRG 470 Undergraduate Engineering Teaching

Spring. 3 credits.

Engineering juniors and seniors can now earn graduation credit while helping freshmen learn mathematics, physics, or engineering design. This course introduces apprentice teachers to collaborative learning, pedagogical theory, interpersonal/diversity issues, and practical tools for educational innovation. This course is an approved elective and can be applied toward the Honors Degree in Electrical Engineering. A 3.0 GPA is strongly recommended.

ENGRG 501 Bioengineering Seminar
Fall, spring. 1 credit. Primarily for juniors, seniors, and graduate students.
M. L. Shuler.
Broad survey of all aspects of bioengineering, including biomedical, bioprocess, biological, and bioenvironmental engineering and aspects of biotechnology. Sessions may be technical presentations or discussions.

ENGRG 605 Fundamentals of Biomedical Engineering I
Fall. 1–4 credits (1 credit per section). Prerequisites: graduate standing in Engineering or Science; PHYS 213 and MATH 294 or equivalent. Undergraduates must have permission of instructor and have completed ABEN 454, CHEME 481, **or** M&AE 465. S-U grades optional for students **not** majoring or minoring in biomedical engineering.
A series of four-week modules on specialized topics. Coordinator: M. L. Shuler.

605.1 Cellular Dynamics and Cancer
1 credit. Lec. T R 1:25–2:40. Aug. 28-Sept. 25. M. L. Shuler.
Basic concepts of cell biology. Mathematical models of cell cycle, receptor-mediated signaling, and cell adhesion. Conceptual approaches for engineering solutions to cancer.

605.2 Physiological Systems
1 credit. Lec. T R 1:25–2:40. Sept. 29-Oct. 30. M. L. Shuler, W. L. Olbricht.
Emphasis on development of physiologically-based pharmacokinetic models for drug delivery and on models of cardiovascular system, particularly blood flow.

605.3 Biomaterials
1 credit. Lec. T R 1:25–2:40. Nov. 4-Dec. 4. C. C. Chu.
The main objective of the biomaterials module is to provide students with an effective background in a wide range of biomaterials that include polymers, metals/alloys, and ceramics and that are currently used in human body repair. After student's completion of this module, they should have the basic and some in-depth knowledge of what biomaterials are made of, how biomaterials contribute to the saving of human lives, the criteria of materials for biomedical use, biocompatibility, failure modes of biomaterials, and the current R/D activities in biomaterials, challenges that biomaterials are facing and future direction of R/D in biomaterials.

605.4 Biomedical Engineering Project
1 credit. Organizational Meeting. T 3:35–4:25. Nov. 4-Dec. 4. M. L. Shuler.
Students will work in teams on a design problem of their choice related to development of a biomedical device or procedure. Each team will present an oral report and a written report.

ENGRG 606 Fundamentals of Biomedical Engineering II
Spring. 1–4 credits. Prerequisites: Graduate standing in Engineering or Science; PHYS 213 and MATH 294 or equivalent. Undergraduates must have permission of instructor and have completed ABEN 454, CHEME 481, **or** M&AE 465. S-U grades optional for students **not** majoring or minoring in biomedical engineering.
A series of 1 and 2-credit modules on specialized topics. Coordinator: M. L. Shuler

606.1 Artificial Organs and Tissue Engineering
1 credit. Lec. T R 1:25–2:40. Jan. 20-Feb. 17. W. M. Saltzman. Prerequisite: ENGRG 605, Section 03 (Biomaterials).
An introduction to the use of cells, biological molecules, and synthetic materials as the basis for building artificial organs and encouraging tissue regeneration. The section will discuss the physiological and engineering issues underlying the use of synthetic, extracorporeal systems (e.g., membrane-based dialysis devices), composite implantable materials (e.g., drug-delivery systems and nerve regeneration guides), and hybrid cell/polymer implantable systems (e.g., engineered tissues).

606.2 Biomedical Instrumentation and Diagnosis
1 credit. Lec. T R 1:25–2:40. Feb. 19-March 26. C. D. Montemagno.
Perspective on the use of advanced instrumentation for the diagnosis and treatment of disease and the investigation of fundamental biological processes. The basic theory and application of different microscopic and spectroscopic methods, imaging tomographies, and micro-electromechanical devices to biological systems will be explored.

606.3 Biomechanics of Musculoskeletal Systems
2 credits. Lec. T R 1:25–4:40. March 31-April 30. D. L. Bartel, C. E. Farnum.
Integrated lecture/laboratory experience. The anatomy and function of the canine hindlimb will be explored in dissection laboratories and through demonstration of a non-invasive technique, computed tomography. Methods of approximating functional joint loads will be discussed, and physical testing will be demonstrated. A computer model of the stifle (knee) joint will be created by combining knowledge of the anatomy and the mechanical environment.

Introduction to Engineering Courses

Courses in this category are freshman-level courses intended to introduce students to various aspects of engineering. They have no prerequisites and are always cross-listed with a department.

ENGRI 110 The Laser and Its Applications in Science, Technology, and Medicine (also A&EP 110)
Fall, spring. 3 credits.
The principles of laser action, types of laser systems, elements of laser design, and applications of lasers in science, technology, and medicine are discussed. In the laboratory students build and operate a nitrogen laser and a tunable dye laser. Demonstration experiments with several types of lasers illustrate phenomena such as holography, laser processing of materials, and Raman spectroscopy.

ENGRI 111 Materials by Design (also MS&E 111)
Fall. 3 credits. E. P. Giannelis.
Explores the relationship between atomic structure and macroscopic properties of such diverse materials as metals, ceramics, polymers, and semiconductors. Hands-on project involves dissecting and analyzing various consumer products like a disposable camera or portable cassette player. Emphasis is placed on materials identification and their selection to perform an engineering function.

ENGRI 112 Introduction to Chemical Engineering (also CHEME 112)
Fall, spring. 3 credits. Limited to freshmen. T. M. Duncan, C. Cohen.
Design and analysis of processes involving chemical change. Strategies for design, such as creative thinking, conceptual blockbusting, and (re)definition of the design goal, in the context of contemporary chemical engineering. Methods for analyzing designs, such as mathematical modeling, empirical analysis by graphics, and dynamic scaling through dimensional analysis, to assess product quality, economics, safety, and environmental issues.

ENGRI 113 Introduction to Environmental Systems (also CEE 113)
Fall. 3 credits. Not open (without instructor's permission) to upper-division engineering students, who should take CEE 120 instead. C. A. Shoemaker.
Introduction to analysis, management, and modeling of environmental systems. Discussion of physical, chemical, and biological processes affecting environmental quality. Use of computers to simulate environmental phenomena. Examples include management of water resources, ecosystems concepts, solid waste management, and water quality in surface and ground waters.

ENGRI 114 An Introduction to Electrical Engineering Design
Spring. 3 credits.
An introduction to electrical engineering and electronic circuit design. Students work in small groups on a series of electric circuit projects leading to the team design of a working fiber optic transmitter-receiver system. The laboratories and lectures introduce the concepts and principles of electronic circuits and focus upon circuits useful in the design project. Laboratory fee required.

ENGRI 115 Engineering Application of Operations Research (also OR&IE 115)
Fall, spring. 3 credits.
An introduction to the problems and methods of Operations Research and Industrial Engineering focusing on problem areas (including inventory, network design, and resource allocation), the situations in which these problems can be found, and several standard solution techniques. In the computer laboratory, students will encounter problem simulations and use some standard software packages.

ENGRI 116 Modern Structures (also CEE 116)
Fall, spring. 3 credits. Staff.
An introduction to the basic principles of structural engineering and to structural forms. Emphasis is placed on how various types of structures carry loads. Concepts are illustrated by a series of case studies of major structures such as spacecraft, skyscrapers, bridges, shell structures, and dams. The philosophy of engineering design and lessons learned from structural failures and earthquakes are discussed. A semester project involves the design and construction of a small balsa-wood bridge.

ENGRI 117 Introduction to Mechanical Engineering (also M&AE 117)
Fall or spring to be determined. 3 credits.
An introduction to topics of current interest in mechanical engineering. Specific topics vary

from offering to offering. Students are urged to check in Upson 112 for details.

ENGRI 118 Design Integration: A Portable CD Player (also MS&E 118 and T&AM 118)
Spring. 3 credits. W. Sachse.
This course examines the roles of various engineering disciplines on the design of a portable compact disc (CD) player. Students are introduced to elements of mechanical, electrical, materials, environmental, manufacturing, and computer engineering as related to the CD player. Laboratory sessions and demonstrations are used to illustrate the principles of design.

ENGRI 120 Introduction to Biotechnology (also CHEME 120)
Fall. 3 credits. W. M. Saltzman.
Introduction to the fundamental science and engineering that spawned the biotechnology revolution—technologies of cell cultures, DNA, and antibodies—and the relationship between biomedical science, bioengineering, and the growing biomedical product industry. Case studies of the development of biotechnical processes, from discovery to clinical use, will include processes for vaccines, antibiotics, cancer chemotherapy, protein pharmaceuticals, and organ transplantation.

ENGRI 121 Fission, Fusion, and Radiation (also NS&E 121)
Spring. 3 credits.
Lecture-laboratory course on (1) the physical nature and biological effects of nuclear radiation; (2) benefits and hazards of nuclear energy; (3) light-water reactors, breeder reactors, and fusion reactors; and (4) uses of nuclear radiation in research. Laboratory demonstrations involve Cornell's research reactor; detection of nuclear radiation; activation analysis using gamma-ray spectroscopy; and pulsed power generators for fusion research.

ENGRI 122 Earthquake! (also GEOL 122)
Fall. 3 credits. L. D. Brown.
The science of natural hazards and strategic resources is explored. Techniques for locating and characterizing earthquakes, and assessing the damage they cause; methods of using sound waves to image the earth's interior to search for strategic materials; the historical importance of such resources. Seismic experiments on campus to probe for groundwater, the new critical environmental resource.

ENGRI 124 Designing Materials for the Computer (also MS&E 124)
Spring. 3 credits. 3 lectures. C. K. Ober.
Introduces the materials, processes and properties of the semiconductors, polymers, ceramics, and metals used in the microelectronics industry to form integrated circuits, electronic devices and displays. This course examines lithographic processing, metallization, diffusion, ion implantation, oxidation and other processes used in fabricating electronic devices and their packages. The technology of displays will be discussed including liquid crystal displays and light emitting devices.

ENGRI 125 Global Environment (also GEOL 125)
Fall. 3 credits. W. M. White, R. W. Kay.
Wise environmental management requires an understanding of natural chemical interactions. Examines natural chemical cycles among atmosphere, biosphere, hydrosphere, and the solid Earth; the impact of man's activity on them, including the greenhouse effect, ozone hole, acid rain, and water pollution. Laboratory sessions include environmental chemical analysis and computer simulation.

ENGRI 126 Introduction to Telecommunications
Fall. 3 credits. 2 lectures.
This course introduces the technologies that underlie wired and wireless telecommunication systems. The course begins with an introduction to telephony and the public switched telephone network. Modems and cellular telephony are then introduced, along with ISDN and BISDN. The course concludes with an introduction to ATM and TCP/IP. The course will include both lectures and laboratory demonstrations. The students will have the opportunity to design communication systems, and to determine their performance through simulations.

ENGRI 185 Art, Archaeology, and Analysis (also ARKEO 285, ART 372, MS&E 285, NS&E 285, PHYS 200)
Spring. 3 credits. 3 lecs. Does not meet liberal studies distribution requirements. D. Clark.
An interdepartmental course on application of techniques of physical sciences and engineering to cultural research. Archaeological artifacts or works of art are discussed with a focus on historical and technical aspects of their creation and on their analysis by modern methods to deduce geographical origins, to date and authenticate objects, etc.

AGRICULTURAL AND BIOLOGICAL ENGINEERING

Courses in agricultural and biological engineering will be found in the section listing the offerings of the College of Agriculture and Life Sciences and at the department web site <http://www.cals.cornell.edu/dept/aben/>.

APPLIED AND ENGINEERING PHYSICS

A&EP 110 The Laser and Its Applications in Science, Technology, and Medicine (also ENGRI 110)
Fall, spring. 3 credits. This is a course in the Introduction to Engineering series.
For description, see ENGRI 110.

A&EP 264 Computer-Instrumentation Design (also ENGRI 264)
Fall, spring. 3 credits. Prerequisites: COM S 100.
For description, see ENGRD 264.

A&EP 320 Engineering Biophysics: The Physics of Life
Spring. 3 credits. Prerequisites: freshman and sophomore chemistry, physics, math.
Introduction to biophysics for engineers and students interested in bioengineering.

A&EP 321 Mathematical Physics I
Fall, summer. 4 credits. Prerequisite: MATH 294. Intended for upper-level undergraduates in the physical sciences.
Review of vector analysis; complex variable theory, Cauchy-Rieman conditions, complex Taylor and Laurent series, Cauchy integral formula and residue techniques, conformal mapping; Fourier Series; Fourier and Laplace transforms; ordinary differential equations; separation of variables. Texts: *Mathematical Methods for Physicists*, by Arfken; *Mathematical Physics*, by Butkov.

A&EP 322 Mathematical Physics II
Spring. 4 credits. Prerequisite: A&EP 321. Second of the two-course sequence in mathematical physics intended for upper-level undergraduates in the physical sciences.
Partial differential equations, Bessel functions, spherical harmonics, separation of variables, wave and diffusion equations, Laplace, Helmholtz and Poisson's Equations, transform techniques, Green's functions; integral equations, Fredholm equations, kernals; complex variables, theory, branch points and cuts, Riemann sheets, method of steepest descent; tensors, contravariant and covariant representations; group theory, matrix representations, class and character. Texts: *Mathematical Methods for Physicists*, by Arfken; *Mathematical Physics*, by Butkov.

A&EP 330 Modern Experimental Optics (see also PHYS 330)
Fall. 4 credits. Enrollment limited. Prerequisites: PHYS 214 or equivalent. E. Bodenschatz.
A practical laboratory course in basic and modern optics. The various projects cover a wide range of topics from geometrical optics to classical wave properties such as interference, diffraction, and polarization. Each experimental setup is equipped with standard, off-the-shelf optics and opto-mechanical components to provide the students with hands-on experience in practical laboratory techniques currently employed in physics, chemistry, biology and engineering. The students will also be introduced to digital imaging and image processing techniques.

A&EP 333 Mechanics of Particles and Solid Bodies
Fall, summer. 4 credits. Prerequisites: PHYS 112 or 116 and coregistration in A&EP 321 or equivalent or permission of instructor.
Newton's mechanics; constants of the motion; many-body systems; linear oscillations; variational calculus; Lagrangian and Hamiltonian formalism for generalized coordinates; non-inertial reference systems; central-force motion; motion of rigid bodies; small vibrations in multi-mass systems; nonlinear oscillations; basic introduction to relativistic mechanics. Emphasis on mathematical treatments, physical concepts, and applications. (On the level of *Classical Dynamics*, by Marion and Thorton).

A&EP 355 Intermediate Electromagnetism
Fall, summer. 4 credits. Prerequisites: PHYS 214 or 217 and coregistration in A&EP 321 or equivalent, or permission of instructor.
Topics: vector calculus, electrostatics, analytic and numerical solutions to Laplace's equation in various geometries, electric and magnetic multipoles, electric and magnetic materials, energy in fields, quasistatics and magnetic circuit design. Emphasis is on developing proficiency with analyical and numerical solution techniques in order to solve real-world design problems.

A&EP 356 Intermediate Electrodynamics
Spring. 4 credits. Prerequisite: A&EP 355 and coregistration in A&EP 322 or equivalent, or permission of instructor.
Topics: electromagnetic waves, waveguides, transmission lines, dispersive media, radiation, special relativity, interference phenomena. Emphasis on physical concepts and developing ability to design/analyze microwave circuits and antenna arrays.

A&EP 361 Introductory Quantum Mechanics
Spring. 4 credits. Prerequisites: A&EP 333 or PHYS 318; coregistration in A&EP 322 or equivalent and in A&EP 356 or PHYS 326.
A first course in the systematic theory of quantum phenomena. Topics include wave mechanics, the Dirac formalism, angular momentum, the hydrogen atom, and perturbation theory.

A&EP 363 Electronic Circuits (also PHYS 360)
Fall, spring. 4 credits. Prerequisites: PHYS 208 or 213 or permission of the instructor. No previous experience with electronics assumed; however, the course moves quickly through some introductory topics such as basic DC circuits. Fall term usually less crowded. 1 lec, 2 labs. Fall: E. Kirkland; spring: J. Alexander.
Analyze, design, build and experimentally test circuits used in scientific and engineering instrumentation (with discrete components and integrated circuits). Analog circuits: resistors, capacitors, operational amplifiers (linear amplifiers with feedback, oscillators, comparators), filters, diodes and transistors. Digital circuits: combinatorial (gates) and sequential (flip-flops, counters, shift registers) logic. Computer interfacing introduced and used to investigate digital to analog (DAC) and analog to digital conversion (ADC) and signal averaging.

A&EP 403 Introduction to Nuclear Science and Engineering I (also M&AE 458 and NS&E 403)
Fall. 3 credits. Prerequisite: PHYS 214 or MATH 294.
For description see NS&E 403.

A&EP 423 Statistical Thermodynamics
Fall. 4 credits. Prerequisite: introductory three-semester physics sequence plus one year of junior-level mathematics.
Quantum statistical basis for equilibrium thermodynamics, microcanonical, canonical and grand canonical ensembles, and partition functions. Classical and quantum ideal gases, paramagnetic and multiple-state systems. Maxwell-Boltzmann, Fermi-Dirac, and Bose-Einstein statistics and applications. Introduction to systems of interacting particles. At the level of *Thermal Physics*, by Kittel and Kroemer, and *Statistical Physics*, by Rosser.

A&EP 434 Continuum Physics
Spring. 4 credits. Prerequisites: A&EP 333 and 356 or equivalent.
Elasticity and Fluid Mechanics: Basic phenomena of elasticity, simple beams, stress and strain tensors, materials equations, equations of motion, general beam equations, waves; Fluids: basic phenomena, Navier Stokes equation, scaling laws, Reynolds and Froude numbers, Poisseuille flows, Stokes drag on sphere, boundary layers, invicid and incompressible flows, potential flow, conservation laws, Bernoulli equation, vorticity and circulation, life of wings, jets, instabilities, introduction to turbulence. Projects in combination with AEP 438 possible. At the level of Lai, Rubin and Krempl, *Continuum Mechanics*, and Tritton, *Introduction to Fluid Mechanics*.

A&EP 438 Computational Engineering Physics
Spring. 3 credits. Prerequisites: COM S 100, A&EP 321, 333, 355, 361, or equivalent, or permission of instructor; co-registration in 361 permitted.
Numerical computation (derivatives, integrals, differential equations, matrices, boundary-value problems, relaxation, Monte Carlo methods, etc.) will be introduced and applied to engineering physics problems that cannot by solved analytically (three-body problem, electrostatic fields, quantum energy levels, etc.). Computer programming required (in C or optionally C++, FORTRAN, or Pascal). Some prior exposure to programming assumed but no previous experience with C assumed.

A&EP 440 Quantum and Nonlinear Optics
Spring. 4 credits. Prerequisites: A&EP 356, A&EP 361 or equivalent.
An introduction to the fundamentals of the interaction of laser light with matter. Topics include the propagation of laser beams in bulk media and in guided-wave structures, the origins of optical nonlinearities, harmonic generation, self-focusing, optical bistability, propagation of ultrashort pulses, solitons, optical phase conjugation, optical resonance and two-level atoms, atom cooling and trapping, multiphoton processes, spontaneous and simulated scattering, ultra-intense laser-matter interactions.

A&EP 450 Introductory Solid State Physics (also PHYS 454)
Fall. 4 credits. Prerequisites: A&EP 361 or equivalent, co-enrollment in A&EP 423 or equivalent.
An introduction to the physics of crystalline solids. Crystal structures; electronic states; lattice vibrations; metals, insulators and semiconductors. The majority of the course will address the foundations of the subject, but some time will be devoted to modern and/or technologically-important topics such as quantum size effects. At the level of *Introduction to Solid State Physics* by Kittel.

A&EP 484 Introduction to Controlled Fusion: Principles and Technology (also ELE E 484, and NS&E 484)
For description, see NS&E 484.

A&EP 490 Independent Study in Engineering Physics
Fall, spring. Credit to be arranged.
Laboratory or theoretical work in any branch of engineering physics under the direction of a member of the faculty. The study can take a number of forms; for example, design of laboratory apparatus, performance of laboratory measurements, computer simulation or software developments, theoretical design and analysis. Details to be arranged with respective faculty member.

A&EP 550 Applied Solid State Physics
Spring. 3 credits. Prerequisites: A&EP 356, 361, 423, 450 (or equivalent)
Directed at students who have had an introductory course in solid state physics at the level of Kittel. This course will concentrate on the application of the quantum mechanical theory of solid state physics to semiconductor materials, solid state electronic devices, solid state detectors and generators of electromagnetic radiation, superconducting devices and materials, the nonlinear optical properties of solids, ferromagnetic materials, nanoscale devices and mesoscopic quantum mechanical effects. The course will stress the basic, fundamental physics underlying the applications rather than the applications themselves. At the level of *Introduction to Applied Solid State Physics* by Dalven.

A&EP 606 Introduction to Plasma Physics (also ELE E 581)
For description, see ELE E 581.

A&EP 607 Basic Plasma Physics (also ELE E 582)
For description, see ELE E 582.

A&EP 609 Nuclear Physics for Applications (also NS&E 509)
For description, see NS&E 509.

A&EP 612 Nuclear Reactor Theory
Fall. 4 credits. Prerequisites: a year of advanced calculus and some nuclear physics. Offered on demand.
Physical theory of fission reactors. Fission and neutron interactions with matter; theory of neutron diffusion; slowing down and thermalization; calculations of criticality and neutron-flux distribution in nuclear reactors. Reactor kinetics. At the level of *Nuclear Reactor Theory*, by Lamarsh.

A&EP 633 Nuclear Reactor Engineering
Fall. 4 credits. Prerequisite: introductory course in nuclear engineering. Offered on demand.
The fundamentals of nuclear reactor engineering, reactor siting and safety, fluid flow and heat transfer, control, environmental effects, and radiation protection.

A&EP 638 Intense Pulsed Electron and Ion Beams: Physics and Technology
Spring. 2 credits. Prerequisites: A&EP 606 (ELE E 581) and 607 (ELE E 582) or equivalent, or permission of instructor. Offered when demand warrants.
Topics include (1) theoretical aspects of intense electron and ion beams, such as equilibria and stability; (2) technology of intense beam production, such as pulsed-power generator principles, and electron and ion diode operation; and (3) applications of intense beams, such as to controlled fusion, microwave generation, and laser pumping. Extensive discussion of experimental results.

A&EP 651 Nuclear Measurements Laboratory
Spring. 4 credits. Prerequisite: A&EP 609 or equivalent. Primarily for graduate students in nuclear fields. A less-intensive related course, NS&E 551, is intended for students in non-nuclear fields in which nuclear methods are used. Offered on demand.
Lectures on interaction of radiation with matter, radiation protection, and nuclear instruments. Experiments in radiation detection, attenuation, and measurement; activation analysis; neutron radiography; reactor physics. The TRIGA reactor and the Zero Power Reactor are used. At the level of *Radiation Detection and Measurement*, by Knoll.

A&EP 661 Microcharacterization
Spring. 3 credits. Prerequisites: introductory three-semester physics sequence or an introductory course in modern physics. At the senior/first-year graduate level.
The basic physical principles underlying the many modern microanalytical techniques available for characterizing materials from volumes less than a cubic micron. Discussion centers on the physics of the interaction process by which the characterization is performed, the methodology used in performing the characterization, the advantages and limitations of each technique, and the instrumentation involved in each characterization method.

A&EP 662 Micro/Nano-fabrication and Processing
Fall. 3 credits.
An introduction to the fundamentals of micro and nano-fabricating and patterning thin-film materials and surfaces, with emphasis on electronic materials, with emphasis on electronic and optical materials, micromechanics, and other applications. Vacuum and plasma thin-film deposition processes. Photon, electron, X-ray, and ion-beam lithography. Techniques for pattern replication by plasma and ion processes. Emphasis is on understanding the physics and materials science that define and limit the various processes. At the level of Brodie and Muray.

A&EP 711 Principles of Diffraction (also MS&E 610)
Spring. 4 credits. Offered alternate years.
Introduction to diffraction phenomena as applied to solid-state problems. Scattering and absorption of neutrons, electrons, and X-ray beams, with particular emphasis on synchrotron radiation X-ray sources. Diffraction from two- and three-dimensional periodic lattices. Fourier representation of scattering centers and the effect of thermal vibrations. Diffraction from almost periodic structures, surface layers, gases, and amorphous materials. Survey of dynamical diffraction from perfect and imperfect lattices. Several laboratory experiments will be conducted.

A&EP 751/752 M ENG Project
751, fall and spring. 6–12 credits to be arranged. Required for candidates for the M.Eng. (Engineering Physics) degree.
Independent study under the direction of a member of the university faculty. Students participate in an independent research project through work on a special problem related to their field of interest. A formal and complete research report is required.

A&EP 753 Special Topics Seminar in Applied Physics
Fall. 1 credit. Prerequisite: undergraduate physics. Required for candidates for the M.Eng. (Engineering Physics) degree and recommended for seniors in engineering physics.
Special topics in applied science, with focus on areas of applied physics and engineering that are of current interest. Subjects chosen are researched in the library and presented in a seminar format by the students. Effort is made to integrate the subjects within selected subject areas such as atomic, biological, computational, optical, plasma, and solid-state physics, or microfabrication technology, as suggested by the students and coordinated by the instructor.

CHEMICAL ENGINEERING

CHEME 112 Introduction to Chemical Engineering (also ENGRI 112)
Fall, spring. 3 credits. Limited to freshmen. T. M. Duncan, C. Cohen.
For description, see ENGRI 112.

CHEME 120 Introduction to Biotechnology (also ENGRI 120)
Fall. 3 credits. W. M. Saltzman.
For description, see ENGRI 120.

CHEME 219 Mass and Energy Balances (also ENGRD 219)
Fall. 3 credits. Corequisite: physical or organic chemistry or permission of instructor. P. Clancy.
For description, see ENGRD 219.

CHEME 301 Nonresident Lectures
Spring. 1 credit. P. Clancy.
Lecturers from industry and from selected departments of the university provide information to assist students in their post-graduate plans.

CHEME 313 Chemical Engineering Thermodynamics
Fall. 4 credits. Corequisite: physical chemistry. A. Z. Panagiotopoulos.
A study of the first and second laws, with application to batch and flow processes. Thermodynamic properties of fluids; applications of thermodynamics to compressors, power cycles, refrigeration; thermodynamic analysis of processes. Thermodynamics of mixtures, phase equilibria and phase diagrams. Estimation methods. Heat effects, chemical equilibria.

CHEME 323 Fluid Mechanics
Fall. 3 credits. Prerequisites: CHEME 219 and engineering mathematics sequence. P. H. Steen.
Fundamentals of fluid mechanics. Macroscopic and microscopic balances. Applications to problems involving viscous flow.

CHEME 324 Heat and Mass Transfer
Spring. 3 credits. Prerequisite: CHEME 323. W. L. Olbricht.
Fundamentals of heat and mass transfer. Macroscopic and microscopic balances. Applications to problems involving conduction, convection, and diffusion.

CHEME 332 Analysis of Separation Processes
Spring. 4 credits. Prerequisites: CHEME 313 and 323. K. E. Gubbins.
Analysis of separation processes involving phase equilibria and mass transfer. Phase equilibria; binary and multicomponent distillation; liquid-liquid extraction; gas absorption, absorption, membrane separations.

CHEME 390 Reaction Kinetics and Reactor Design
Spring. 3 credits. Prerequisites: CHEME 313 and 323. D. L. Koch.
A study of chemical reaction kinetics and principles of reactor design for chemical processes.

CHEME 391 Physical Chemistry I (also CHEM 391)
For description, see CHEM 391.

CHEME 432 Chemical Engineering Laboratory
Fall. 4 credits. Prerequisites: CHEME 323, 324, 332, and 390. Staff.
Laboratory experiments in fluid dynamics, heat and mass transfer, kinetics, other operations. Correlation and interpretation of data. Technical report writing.

CHEME 462 Chemical Process Design
Spring. 4 credits. Prerequisite: CHEME 432. Staff.
A consideration of process and economic alternatives in selected chemical processes; design and assessment.

CHEME 472 Process Control
Fall. 3 credits. Prerequisites: CHEME 324 and 390. J. R. Engstrom.
Analysis of the dynamics of chemical processes and design of feedback and feedforward control systems. Laplace transform techniques; stability analysis; frequency-response analysis. An introduction to multivariable control.

CHEME 481 Biomedical Engineering
Spring. 3 credits. Prerequisite: CHEME 324 or equivalent or permission of instructor. W. M. Saltzman.
Special topics in biomedical engineering, including cell separations, blood flow, design of artificial devices, biomaterials, image analysis, biological transport phenomena, pharmacokinetics and drug delivery, biomedical transducers (ECG and pace makers), and analysis of physiological processes such as adhesion, mobility, secretion, and growth.

CHEME 490 Undergraduate Projects in Chemical Engineering
Fall, spring. Variable credit.
Research or studies on special problems in chemical engineering.

CHEME 491 Undergraduate Teaching in Chemical Engineering
Fall, spring. 1 credit.
Methods of instruction in chemical engineering acquired through discussions with faculty and by assisting with the instruction of freshmen and sophomores.

CHEME 520 Chemical, Pharmaceutical, and Food Processing
Spring. Variable to 3 credits. Prerequisite: seniors or M.Eng. students with one term of college chemistry. C. Cohen, M. L. Shuler, and S. Mulvaney.
This course consists of three equal parts, each worth one credit. The chemical part is open to non-chemical engineers only and covers process fundamentals, design, and control of continuous large-scale chemical processes. Pharmaceutical processing covers fermentation, purification, and sterilization. Food processing emphasizes food preservation principles and technology.

CHEME 562 Managing Chemical Process Design
Fall. 1 or 2 credits. Prerequisite: CHEME 462. K. E. Ackley.
Guidance and evaluation of chemical process designs developed by teams of chemical engineers.

CHEME 564 Design of Chemical Reactors
Spring. 3 credits. Prerequisite: CHEME 390 or equivalent. P. Harriott.
Design, scale-up, and optimization of chemical reactors with allowance for heat and mass transfer and nonideal flow patterns. Homework problems feature analysis of published data for gas-solid, gas-liquid, and three-phase reaction systems.

CHEME 565 Design Project
Fall, spring. 3 or 6 credits. Required for students in the M.Eng.(Chemical) program.
Design study and economic evaluation of a chemical processing facility, alternative methods of manufacture, raw-material preparation, food processing, waste disposal, or some other aspect of chemical processing.

CHEME 590 Special Projects in Chemical Engineering
Fall, spring. Variable credit. Limited to graduate students.
Non-thesis research or studies on special problems in chemical engineering.

CHEME 605 Fundamentals of Biomedical Engineering I (also ENGRG 605)
For description, see ENGRG 605.

CHEME 606 Fundamentals of Biomedical Engineering II (also ENGRG 606)
For description, see ENGRG 606.

CHEME 640 Polymeric Materials
Fall. 3 credits. F. Rodriguez.
Chemistry and physics of the formation and characterization of polymers. Principles of fabrication.

CHEME 643 Introduction to Bioprocess Engineering
Fall. 3 credits. Prerequisite: CHEME 390 or permission of instructor. No prior background in the biological sciences required. M. L. Shuler.
A discussion of principles involved in using microorganisms, tissue cultures, and enzymes for processing. Application to food, fermentation, and pharmaceutical industries and to biological waste treatment.

[CHEME 645 Advanced Concepts in Biological Engineering
Spring. 3 credits. Prerequisite: CHEME 643 or equivalent or permission of instructor. Not offered 1997–98.
Fundamentals of biochemical and biomedical engineering, with additional emphasis on cell and membrane biophysics. Topics include cell-surface receptor phenomena, protein diffusion, cell adhesion, membrane biophysics, cell motility and growth, mathematical immunology, virus binding and infection, enzyme catalysis, bioseparation, and genetically modified organisms.]

CHEME 656 Separations Using Membranes or Porous Solids
Spring. 3 credits. Prerequisites: CHEME 324 and 332. Not offered spring 1997; next offered spring 1998. P. Harriott.
Diffusion of small molecules in gases, liquids, and solids. Membrane separation processes including gas separation, pervaporation, reverse osmosis, and ultrafiltration. Purification of gases and liquids by adsorption, ion exchange, and chromatography.

CHEME 661 Air Pollution Control
Fall. 3 credits. P. Harriott.
Origin of air pollutants, U.S. emission standards, dispersion equations. Design of equipment for removal of particulate and gaseous pollutants formed in combustion and chemical processing.

CHEME 675 Synthetic Polymer Chemistry (also MS&E 671 and CHEM 671)
Fall. 4 credits. Prerequisites: CHEM 359–360 or equivalent or permission of instructor.
For description, see CHEM 671.

CHEME 681 Dynamics of Colloidal Systems
Fall. 3 credits. Prerequisite: basic understanding of thermodynamics and fluid dynamics. Offered alternate years. A. Z. Panagiotopoulos.
Fundamental descriptions of colloidal systems under equilibrium and non-equilibrium conditions. Phase equilibria of surfactant systems, thermodynamics of micelle formation, forces between colloidal particles, electrokinetic phenomena, flocculation and aggregation, transport of surfactant in interfacial systems, stability of emulsions, and dynamics of thin films. Open to advanced undergraduates and graduate students from all fields.

CHEME 711 Advanced Chemical Engineering Thermodynamics
Fall. 3 credits. Prerequisite: CHEME 313 or equivalent. K. E. Gubbins.
Postulatory approach to thermodynamics. Legendre transformations. Equilibrium and stability of general thermodynamic systems. Applications of thermodynamic methods to advanced problems in chemical engineering. Introduction to statistical mechanical ensembles, phase transitions, Monte Carlo methods, and theory of liquids.

CHEME 713 Chemical Kinetics and Dynamics
Spring. 3 credits. Prerequisite: CHEME 390 or equivalent. J. R. Engstrom.
Microscopic and macroscopic viewpoints. Connections between phenomenological chemical kinetics and molecular reaction dynamics. Reaction cross sections, potential energy surfaces, and dynamics of bimolecular collisions. Molecular beam scattering. Transition state theory. Unimolecular reaction dynamics. Complex chemically reacting systems: reactor stability, multiple steady states, oscillations, and bifurcation. Reactions in heterogeneous media. Free-radical mechanisms in combustion and pyrolysis.

CHEME 731 Advanced Fluid Mechanics and Heat Transfer
Fall. 3 credits. Prerequisites: CHEME 323 and 324 or equivalent. D. L. Koch.
Derivation of the equations of motion for Newtonian fluids. Low Reynolds number fluid dynamics, lubrication theory, inviscid fluid dynamics. Boundary layer theory. Convective and conductive heat transfer.

CHEME 732 Diffusion and Mass Transfer
Spring. 2 credits. Prerequisite: CHEME 731 or equivalent. P. H. Steen.
Conservation equations in multicomponent systems, irreversible thermodynamics, dispersion, and Brownian diffusion. Mass transfer for convective diffusion in liquids. Application to a variety of problems such as coagulation of aerosols, diffusion through films and membranes, liquid-liquid extraction, chemical vapor deposition, polymer rheology and diffusion, and reaction-diffusion systems.

CHEME 741 Selected Topics in Biochemical Engineering
Fall. 1 credit (may be repeated for credit). Prerequisite: CHEME 643 or permission of instructor. M. L. Shuler and W. M. Saltzman.
Discussion of current topics and research in biochemical engineering for graduate students.

[CHEME 745 Physical Polymer Science I
Fall. 3 credits. Co-requisite: CHEME 711 or equivalent. Offered alternate years. Not offered 1997–98. C. Cohen.
Thermodynamic properties of dilute, semidilute, and concentrated solutions from both classical and scaling approaches. Characterization techniques of dilute solutions: osmometry, light scattering, viscometry, and sedimentation. Rubber elasticity; mechanical and thermodynamic properties of gels. Polymer melts: equations of state and glass transition phenomena.]

CHEME 751 Mathematical Methods of Chemical Engineering Analysis
Fall. 4 credits. A. B. Anton.
Application of advanced mathematical techniques to chemical engineering analysis. Mathematical modeling, scaling, regular and singular perturbation, multiple scales, asymptotic analysis. Linear and nonlinear ordinary differential equations, partial differential equations.

CHEME 753 Analysis of Nonlinear Systems: Stability, Bifurcation, and Continuation
Fall. 3 credits. Prerequisite: CHEME 751 or equivalent. Offered alternate years. P. H. Steen.
Elements of stability and bifurcation theory. Branch-following techniques. Stability of discrete and continuous systems. Application to elasticity, reaction-diffusion, and hydrodynamic systems using software for continuation problems.

CHEME 772 Theory of Molecular Liquids
Spring. 3 credits. Prerequisite: CHEME 711 or equivalent.
Theory of intermolecular forces, and equilibrium statistical mechanics for nonspherical molecules. Distribution functions. Applications to thermodynamics of such fluids using integral equation and perturbation theory techniques. Mixture properties, phase diagrams for mixtures with polar or quadrupolar components. Surface properties.

CHEME 774 Atomistic Simulation of Materials
Spring. 3 credits. Prerequisite: competence in FORTRAN, PASCAL, or C. Prior knowledge of statistical mechanics helpful. Offered alternate years. A. Z. Panagiotopoulos.
The statistical mechanical theory behind Monte-Carlo and Molecular-Dynamics computer-simulation techniques. Strong emphasis is placed on students writing their own MC and MD code. Calculation of distribution functions, thermodynamic, kinetic and structural properties. Introduction to the application of computer graphics to simulation. Interparticle forces and application of atomistic simulation of systems containing metals, semiconductors, and biological materials. Issues of code efficiency and vectorization.

CHEME 790 Seminar
Fall, spring. 1 credit each term.
General chemical engineering seminar required of all graduate students in the Field of Chemical Engineering.

CHEME 792 Advanced Seminar in Thermodynamics
Fall, spring. 1 credit.
A forum for talks by graduate students and faculty members on topics of current interest in thermodynamics and statistical mechanics.

CHEME 890 Thesis Research
Fall, spring. Variable credit.
Thesis research for the M.S. degree in chemical engineering.

CHEME 990 Thesis Research
Fall, spring. Variable credit.
Thesis research for the Ph.D. degree in chemical engineering.

CIVIL AND ENVIRONMENTAL ENGINEERING

General

CEE 113 Introduction to Environmental Systems (also ENGRI 113)
Fall. 3 credits. C. A. Shoemaker.
For description, see ENGRI 113.

CEE 116 Modern Structures (also ENGRI 116)
Fall, spring. 3 credits. G. G. Deierlein and staff.
For description, see ENGRI 116.

CEE 120 Readings on the Environment
Fall. 1 credit. C. A. Shoemaker.
A reading course from an introductory environmental text. Topics include structure and dynamics of ecosystems, water habitats and communities, water resources, toxic-waste pollution of surface and groundwater, international water-pollution problems, energy resources, nuclear-waste disposal, hydroelectric power, environmental carcinogens. Not available to students receiving credit for ENGRI 113 or Natural Resources 201.

CEE 241 Engineering Computation (also ENGRD 241)
Spring. 3 credits. Prerequisites: COM S 100 and MATH 293. Corequisite: MATH 294. J. F. Abel.
For description, see ENGRD 241.

CEE 304 Uncertainty Analysis in Engineering
Fall. 4 credits. Prerequisite: first-year calculus. J. R. Stedinger.
An introduction to probability theory and statistical techniques, with examples from civil, environmental, agricultural, and related disciplines. The course covers data presentation, probability theory, commonly used probability distributions describing natural phenomona and material properties, parameter estimation, confidence intervals, hypothesis testing, simple linear regression, and nonparametric statistics. Examples include structural reliability, and models of vehicle arrivals.

CEE 309 Special Topics in Civil and Environmental Engineering
Fall, spring. 1–6 credits. Staff.
Supervised study by individuals or groups of upper-division students on an undergraduate research project or on specialized topics not covered in regular courses.

CEE 400 Senior Honors Thesis
Fall, spring. 1–6 credits. Staff.
Available to students admitted to the CEE Honors Program. Supervised research, study, and/or project work resulting in a written report or honors thesis.

CEE 401 Undergraduate Engineering Teaching in CEE
Fall, spring. 1–3 credits. Prerequisite: permission of instructor. Staff.
Methods of instruction developed through discussions with faculty and by assisting with the instruction of undergraduates under the supervision of faculty.

CEE 501 Civil and Environmental Engineering Design Project I
Fall. 3 credits. Required for students in the M.Eng.(Civil) program. Staff.
Design of major civil engineering project. Planning and preliminary design in fall term; final design in January intersession (CEE 502).

CEE 502 Civil and Environmental Engineering Design Project II
Spring (work required during January intersession). 3 credits. Required for students in the M.Eng.(Civil) program. Prerequisite: CEE 501. Staff.
A continuation of CEE 501.

CEE 503 Professional Practice in Engineering
Spring. 3 credits. Required for and limited to students in the M.Eng.(Civil) program. Staff.
Financial, legal, regulatory, ethical, and business aspects of engineering practice are examined in detail. Students are expected to develop their understanding of the interrelations among the physical, social, economic, and ethical constraints on engineering design.

CEE 504 Environmental Law and Regulation
Spring. 3 credits. W. G'Sell.
The course is designed to provide an overview of environmental law, emphasizing aspects relevant to civil and environmental engineering. The focus is on issues of water supply, water pollution control, waste management and environmental remediation. This course is geared to students participating in the environmental management concentration. Class size will be limited to 25 students.

CEE 601 Water Resources and Environmental Engineering Seminar
Fall. 1 credit.
Presentation of topics of current interest.

Remote Sensing

CEE 411 Remote Sensing: Environmental Applications (also SCAS 461)
Spring. 3 credits. Prerequisite: permission of instructor. Staff.
A survey of how remote sensing and resource inventory methods are applied to field-based studies of environmental systems. Laboratory emphasis is on using maps, spatial databases, global positioning systems, and aerospace imagery to discriminate, measure, inventory, and monitor environmental resources.

[CEE 610 Remote Sensing Fundamentals (also SCAS 660)
Fall. 3 credits. Prerequisite: permission of instructor. Not offered 1997–98. W. D. Philpot.
An introduction to equipment and methods used in obtaining information about earth resources and the environment from aircraft or satellite. Coverage includes sensors; sensor and ground-data aquisition; data analysis and interpretation; and project design.]

[CEE 615 Digital Image Processing
Spring. 3 credits. Prerequisites: facility with algebra and trigonometry (e.g., MATH 109) and statistics (e.g., CEE 304 or ARME 310), or permission of instructor. Not offered 1997–98; next offered 1998–99. W. D. Philpot.
An introduction to digital image-processing concepts and techniques, with emphasis on remote-sensing applications. Topics include image acquisition, enhancement procedures, spatial and spectral feature extraction, and classification. Assignments will require the use of image-processing software and graphics.]

CEE 617 Project—Remote Sensing
On demand. 1–6 credits. W. D. Philpot.
Students may elect to undertake a project in remote sensing. The work is supervised by a professor in this subject area.

CEE 618 Special Topics—Remote Sensing
On demand. 1–6 credits. W. D. Philpot.
Supervised study in small groups on one or more special topics not covered in the regular courses. Special topics may be of a theoretical or applied nature.

CEE 710 Research—Remote Sensing
On demand. 1–6 credits. W. D. Philpot.
For students who want to study one particular area in depth. The work may take the form of laboratory investigation, field study, theoretical analysis, or development of design procedures.

CEE 810 Thesis—Remote Sensing
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. W. D. Philpot.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Environmental and Public Systems

See also CEE 113, CEE 120, CEE 241, CEE 304, and CEE 597.

CEE 323 Engineering Economics and Management (also ENGRG 323)
Spring; usually offered in summer for Engineering Co-op Program. 3 credits. Primarily for juniors and seniors. D. P. Loucks.
For description, see ENGRG 323.

CEE 423 Environmental Quality Systems Analysis
Spring. 3 credits. Prerequisites: MATH 294 and systems (CEE 323). Intended for undergraduates who have not taken OR&IE 320 or ABEN 475. Most lectures concurrent with CEE 623. C. A. Shoemaker.
Applications of optimization, simulation methods, and uncertainty analysis to the design and operation of facilities for managing the quality of surface and ground water. See CEE 623 for a description of environmental applications. CEE 423 students do additional work on optimization fundamentals and do not do the CEE 623 main design project.

CEE 528 Public Political Economy (also ECON 539)
Spring. 4 credits. R. E. Schuler.
For description, see ECON 539.

CEE 529 Water and Environmental Resources Problems and Policies
Spring. 3 credits. Intended primarily for graduate engineering and non-engineering students but open to qualified upperclass students. Prerequisite: permission of instructor. D. J. Allee and L. B. Dworsky.
Evaluation, appraisal, and prospects for problems involving water and environmental resources. Organization and public policies in the federal system.

CEE 620 Water-Resources Systems I
Fall. 3 credits. Prerequisite: CEE 323 or equivalent. D. P. Loucks.
Development and application of deterministic and stochastic optimization and simulation models for water-resources planning and management. River-basin modeling, including reservoir design and operation, irrigation planning and operation, hydropower-capacity development, flow augmentation, flood control and protection, and water-quality prediction and control.

[CEE 621 Water-Resources Systems II: Stochastic Hydrology
Spring. 3 credits. Prerequisites: CEE 304 and 620 or permission of instructor. Not offered 1997–98. J. R. Stedinger.
Course examines statistical, time series, and stochastic optimization methods used to address water resources problems. Statistical issues include maximum likelihood, and moments estimators; censored datasets and historical information; probability plotting; Bayesian inference; index flood methods; ARMA models; multivariate stochastic streamflow models; stochastic simulation; and reservoir-operation optimization models.]

CEE 623 Environmental Systems Engineering
Spring. 3 credits. Prerequisites: MATH 294 and optimization (ABEN 475, or OR&IE 320/520) and probability and statistics (CEE 304 or OR&IE 270), or permission of instructor. C. A. Shoemaker.
Applications of optimization, simulation methods, and uncertainty analysis to the prevention and remediation of pollution. Applications include regional waste and wastewater treatment, restoration of dissolved oxygen levels in rivers, and reclamation of contaminated groundwater. Applications use linear programming, integer, dynamic, nonlinear programming, and sensitivity analysis.

CEE 628 Environmental and Water Resources Systems Analysis Seminar
Spring. 1 credit. Prerequisite: permission of instructor. Staff.
Graduate students and faculty members give informal lectures on various topics related to ongoing research in environmental or water resources systems planning and analysis.

CEE 722 Environmental and Water Resources Systems Analysis Research
On demand. 1–6 credits. Prerequisite: permission of instructor. Preparation must be suitable to the investigation to be undertaken. Staff.
Investigations of particular environmental or water resources systems problems.

CEE 729 Special Topics in Environmental or Water Resources Systems Analysis
On demand. 1–6 credits. Staff.
Supervised study, by individuals or small groups, of one or more specialized topics not covered in regular courses.

CEE 820 Thesis—Environmental and Water Resource Systems
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Fluid Mechanics and Hydrology

See also CEE 241 and CEE 655.

CEE 331 Fluid Mechanics
Fall; usually offered in summer for Engineering Co-op Program. 4 credits. Prerequisite: ENGRD 202 (may be taken concurrently). W. H. Brutsaert.
Hydrostatics, the basic equations of fluid flow, potential flow and dynamic pressure forces, viscous flow and shear forces, steady pipe flow, turbulence, dimensional analysis, open-channel flow. Elements of design in water supply systems, canals, and other hydraulic schemes.

CEE 332 Hydraulic Engineering
Spring. 4 credits. Prerequisite: CEE 331. M. L. Weber-Shirk.
Application of fluid-mechanical principles to problems of engineering practice and design: hydraulic machinery, water-distribution systems, open-channel design, river engineering, groundwater flow, and pollutant dispersal. Lectures supplemented by laboratory work and a design project.

CEE 431 Geohydrology (also GEOL 445 and ABEN 471)
Fall. 3 credits. L. Cathles, W. H. Brutsaert.
Intermediate-level study of aquifer geology, groundwater flow, and related design factors. Includes description and properties of natural aquifers, ground water hydraulics, soil water, and solute transport.

CEE 432 Hydrology
Spring. 3 credits. Prerequisite: CEE 331. Intended for undergraduates. Lectures concurrent with CEE 632. W. H. Brutsaert.
Introduction to hydrology as a description of the water cycle and the role of water in the natural environment, and other issues for environmental engineers. See description for CEE 632.

CEE 435 Coastal Engineering
Fall. 4 credits. Prerequisite: CEE 331. P. L.-F. Liu.
Introduction to water wave phenomena, including wave generation, shoaling, refraction, diffraction, and breaking. Applications of wave theories to engineering design problems such as forces on coastal structures and beach erosion in coastal zones. Lectures supplemented by four laboratory assignments and a design project.

[CEE 630 Advanced Fluid Mechanics
Fall. 3 credits. Prerequisite: CEE 331. Not offered 1997–98 and 1998–99. Staff.
Introduction to tensor analysis; conservation of mass, momentum, and energy. Rigorous treatment includes study of exact solutions of the Navier-Stokes equations. Asymptotic approximations at low and high Reynolds numbers. Similitude and modeling. Laminar diffusion of momentum, mass, and heat.]

CEE 631 Flow and Contaminant Transport Modeling in Groundwater
Spring. 3 credits. Prerequisites: MATH 294 or equivalent, ENGRD 241 or experience in numerical methods and programming, and elementary fluid mechanics. P. L. -F. Liu.
Potential flows and their calculation. Numerical methods include finite difference, finite elements, and boundary elements. Fundamental equations of saturated and unsaturated flow in porous media. Flow in fractured media. Numerical modeling of transport in porous media. Diffusion and advective diffusion in one, two, and three dimensions. Anisotropy. Additional terms for reactive substances. The course will include the use of computer programs.

CEE 632 Hydrology
Spring. 3 credits. Prerequisite: CEE 331. W. H. Brutsaert.
Introduction to hydrology as a description of the water cycle and the role of water in the natural environment, and other issues for environmental engineers. Physical and statistical prediction methods for design related to hydrologic processes. Hydrometeorology and evaporation. Infiltration and base flow. Surface runoff and channel routing. Linear and nonlinear hydrologic systems. Storage routing and unit hydrograph methods.

CEE 633 Flow in Porous Media and Groundwater
Fall. 3 credits. Prerequisite: CEE 331. W. H. Brutsaert.
Fluid mechanics and equations of single-phase and multiphase flow; methods of solution. Applications involve aquifer hydraulics, pumping wells; drought flows; infiltration, groundwater recharge; land subsidence; seawater intrusion, miscible displacement; transient seepage in unsaturated materials.

[CEE 634 Boundary Layer Meteorology
Fall. 3 credits. Prerequisite: CEE 331 or permission of instructor. Not offered 1997–98. W. H. Brutsaert.
Physical processes in the lower atmospheric environment: turbulent transport in the atmospheric boundary layer, surface-air interaction, disturbed boundary layers, radiation. Applications include sensible and latent heat transfer from lakes, plant canopy flow and evapotranspiration, turbulent diffusion from chimneys and cooling towers, and related design issues.]

CEE 635 Small and Finite Amplitude Water Waves
Spring. 3 credits. Prerequisite: CEE 435 or equivalent. P. L.-F. Liu.
Review of linear and nonlinear theories of ocean waves. Discussions on the applicability of different wave theories to engineering problems.

[CEE 636 Environmental Fluid Mechanics
Spring. 3 credits. Prerequisite: CEE 655 or permission of instructor. Offered alternate years. Not offered 1997–98. Staff.
Mass- and heat-transport processes in the environment and their interaction with pollutant discharges. Mechanics of discretely and continuously stratified fluids, internal

waves, density currents, selective withdrawal, and baroclinic motions. Flow stability, mixing, and turbulence. Turbulent diffusion and shear flow dispersion, including effects of buoyancy. Convective instabilities and mixed-layer dynamics. Concentrated sources of momentum and buoyancy: jets and plumes and their behavior in the environment. Applications to mixing processes in rivers, lakes, the ocean, and the atmosphere.]

CEE 638 Hydraulics Seminar
Spring. 1 credit. Open to undergraduates and graduates and required of graduate students majoring in hydraulics or hydraulic engineering. P. L. -F. Liu.
Topics of current interest in fluid mechanics, hydraulic engineering, and hydrology.

CEE 639 Special Topics in Hydraulics
On demand. 1–6 credits. Staff.
Special topics in fluid mechanics, hydraulic engineering, or hydrology.

CEE 732 Computational Hydraulics
Fall. 3 credits. Prerequisite: elementary fluid mechanics or permission of instructor. Offered alternate years. Offered 1997–98. Staff.
Numerical methods for solving hydraulics and fluid-mechanics problems. Solutions for elliptic, parabolic, and hyperbolic equations. Finite-difference, finite-element, and boundary-integral methods.

CEE 735 Research in Hydraulics
On demand. 1–6 credits. Staff.
The student may select an area of investigation in fluid mechanics, hydraulic engineering, or hydrology. The work may be either experimental or theoretical in nature. Results should be submitted to the instructor in charge in the form of a research report.

CEE 830 Thesis—Fluid Mechanics and Hydrology
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis resarch topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Geotechnical Engineering

CEE 341 Introduction to Geotechnical Engineering
Spring. 4 credits. Prerequisite: ENGRD 202. F. H. Kulhawy.
Soil as an engineering material. Chemical and physical nature of soil. Engineering properties of soil. Stresses and stress analysis of soil. Basic theory and design for water flow in soil, one-dimensional consolidation of clay and silts, and shear-strength problems. Introduction to slope stability, earth pressure, geosynthetics, and landfill and waste-containment issues. Introduction to laboratory testing. Synthesis of soil analysis and laboratory-test results for the design of engineering structures.

CEE 640 Foundation Engineering
Fall. 3 credits. Prerequisite: CEE 341. F. H. Kulhawy.
Soil exploration, sampling, and in-situ testing techniques. Bearing capacity, stress distribution, and settlement. Design of shallow and deep foundations. Compaction and site preparation. Seepage and dewatering of foundation excavations.

CEE 641 Retaining Structures and Slopes
Spring. 3 credits. Prerequisite: CEE 341. T. D. O'Rourke.
Earth pressure theories. Design of rigid, flexible, braced, tied-back, slurry, and reinforced soil structures. Stability of excavation, cut, and natural slopes. Design problems stressing application of course material under field conditions of engineering practice.

CEE 643 Pavement Engineering (also ABEN 692)
Spring. 4 credits. Limited to engineering seniors and graduate students. Prerequisite: CEE 341 or 362. L. H. Irwin.
For description, see ABEN 692.

CEE 644 Environmental Applications of Geotechnical Engineering
Spring. 3 credits. Prerequisite: CEE 341 or equivalent. T. D. O'Rourke.
Principles of hydrogeology, contaminant migration, and remediation technologies related to geotechnical and environmental engineering. Emphasis on environmental site assessment, site feasibility studies, selection of remediation procedures, and engineered landfills. Design problems are based on real projects and involve visits from practicing engineers.

CEE 648 Seminar in Geotechnical Engineering
Fall, spring. 1 credit. Staff.
Presentation and discussion of topics in current research and practice in geotechnical engineering.

CEE 649 Special Topics in Geotechnical Engineering
On demand. 1–6 credits. Staff.
Supervised study of special topics not covered in the formal courses.

CEE 740 Engineering Behavior of Soils
Fall. 3 credits. Prerequisite: CEE 341. Offered 1997–98 and 1998–99. H. E. Stewart.
Detailed study of the physiochemical nature of soil. Stress states due to geostatic loading and stress-history effects. In-depth evaluation of stress-strain-strength, compressibility, and hydraulic conductivity of natural soils. Field-testing methods for determining properties based on laboratory testing. Laboratory sessions include in-situ field testing, simple index tests, and complete laboratory characterization of important soil properties.

CEE 741 Rock Engineering
Spring. 3 credits. Prerequisite: CEE 341 or permission of instructor. Recommended: introductory geology. Staff.
Geological and engineering classifications of intact rock, discontinuities, and rock masses. Laboratory and field evaluation of properties. Stress states and stress analysis. Design of foundations on, and openings in, rock masses. Analysis of the stability of rock slopes.

CEE 744 Advanced Foundation Engineering
Spring. 2 credits. Prerequisite: CEE 640. Offered 1997–98; not offered 1998–99. F. H. Kulhawy.
A continuation of CEE 640, with detailed emphasis on special topics in soil-structure interaction. Typical topics include lateral and pullout loading of deep foundations, pile group behavior, foundations for offshore structures, foundations for special structures.

CEE 745 Soil Dynamics
Spring. 3 credits. Prerequisite: permission of instructor. H. E. Stewart.
Study of soil behavior under dynamic loading conditions. Foundation design for vibratory loadings. Introductory earthquake engineering including field and laboratory techniques for determining dynamic soil properties and liquefaction potential. Design of embankments and retaining structures under dynamic loading conditions. Laboratory experiments and demonstrations using resonant column and a range of cyclic testing equipment.

[CEE 746 Embankment Dam Engineering
Spring. 2 credits. Prerequisites: CEE 641 and 741, or permission of instructor. Offered 1998–99; not offered 1997–98. F. H. Kulhawy.
Principles of analysis and design for earth and rockfill dams. Materials, construction methods, internal and external stability, seepage and drainage, performance monitoring, abutment and foundation evaluation. Introduction to tailings dams.]

CEE 749 Research in Geotechnical Engineering
On demand. 1–6 credits. Staff.
For the student who wants to pursue a particular geotechnical topic in considerable depth.

CEE 840 Thesis—Geotechnical Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Environmental Engineering

CEE 351 Environmental Quality Engineering
Spring; usually offered in summer for Engineering Co-op Program. 3 credits. L. W. Lion.
Introduction to engineering aspects of environmental quality control. Quality parameters, criteria, and standards for water and wastewater. Elementary analysis pertaining to the modeling of pollutant reactions in natural systems, and introduction to design of unit processes for water and wastewater treatment.

CEE 352 Water Supply Engineering
Fall. 3 credits. Prerequisites: ENGRD 219, CHEM 253, BIOMI 290 and CEE 351. M. Weber-Shirk.
Analysis of contemporary threats to human health from water supply systems. Criteria and standards for potable-water quality. Water-quality control theory. Design of water supply facilities.

CEE 453 Laboratory Research in Environmental Engineering
Spring. 3 credits. Prerequisites: CHEM 253, BIOMI 290, CEE 351 or permission of instructor. M. L. Weber-Shirk.
Laboratory investigations of reactor flow characteristics; acid rain/lake chemistry; contaminated soil-site assessment, risk assessment, and remediation; pollutant

dispersion/transport in rivers; drinking water filtration for pathogen removal; oxygen sag in rivers; and biodegradation in landfills. Design of laboratory experiments, development of laboratory methods, and use of experimental data are emphasized.

CEE 651 Microbiology for Environmental Engineering
Fall. 2 credits. Prerequisite: one semester of college chemistry. J. M. Gossett.
A self-paced autotutorial introduction to fundamental aspects of microbiology, organic chemistry, and biochemistry pertinent to environmental engineering. Course work consists of assigned readings, study questions, and brief exams.

CEE 653 Water Chemistry for Environmental Engineering
Fall. 3 credits. Prerequisite: one semester of college chemistry or permission of instructor. L. W. Lion.
Principles of chemistry applicable to the understanding, design, and control of water and wastewater treatment processes and to reactions in receiving waters. Topics include chemical thermodynamics, reaction kinetics, acid-base equilibria, mineral precipitation/dissolution, and electrochemistry. The focus of the course is on the mathematical description of chemical reactions relevant to engineered processes and natural systems, and the numerical or graphical solution of these problems.

CEE 654 Aquatic Chemistry
Spring. 3 credits. Prerequisite: CEE 653 or CHEM 287–288. J. J. Bisogni.
Concepts of chemical equilibria applied to natural aquatic systems. Topics include acid-base reactions, buffer systems, mineral precipitation, coordination and redox reactions, Eh-pH diagrams adsorption phenomena, humic acid chemistry, and chemical-equilibria computational techniques. In-depth coverage of topics covered in CEE 653.

CEE 655 Pollutant Transport and Transformation in the Environment
Fall. 3 credits. Prerequisite: CEE 331. J. J. Bisogni.
Introduction to the physical transport and chemical and biochemical transformation processes that govern the fate and distribution of pollutants in the environment.

[CEE 658 Sludge Treatment, Utilization, and Disposal
Spring. 3 credits. Prerequisite: CEE 352 or permission of instructor. Not offered 1997–98. R. I. Dick.
Analysis of the quantity and quality of residues produced from municipal and industrial water-supply and pollution-control facilities and other residue-producing processes. Alternatives for reclaiming or disposing of hazardous and nonhazardous residues. Performance of treatment processes for altering sludge properties prior to reuse or ultimate disposal. Considerations in selecting and integrating of sludge-management processes.]

CEE 659 Environmental Quality Engineering Seminar
Spring. 1 credit. Prerequisite: enrollment as graduate student in environmental engineering. Staff.
Presentation and discussion of current research and design projects in environmental engineering.

CEE 750 Research in Environmental Engineering
On demand. 1–6 credits. Staff.
For students who want to study a particular area in depth. The work may take the form of laboratory investigation, field study, theoretical analysis, or development of design and analysis procedures.

CEE 755 Environmental Engineering Processes I
Fall. 3 credits. Prerequisite: previous or concurrent enrollment in CEE 653 or permission of instructor. J. M. Gossett.
Theoretical and engineering aspects of chemical and physical phenomena and processes applicable to the removal of impurities from water, wastewater, and industrial wastes and to their transformation in receiving waters. Analysis and design of treatment processes and systems.

CEE 756 Environmental Engineering Processes II
Spring. 3 credits. Prerequisites: CEE 651 and 755, or permission of instructor. J. M. Gossett.
Theoretical and engineering aspects of biological phenomena and processes applicable to the removal of impurities from water, wastewater, and industrial wastes and to their transformation in receiving waters. Biokinetic analysis and design of biological treatment process.

CEE 757 Environmental Engineering Processes Laboratory I
Fall. 2 credits. Prerequisite: concurrent enrollment in CEE 653 and CEE 755. J. J. Bisogni.
Laboratory studies of aquatic chemistry and physical/chemical processes of environmental engineering. Topics include gravimetric analyses; acids/bases; alkalinity; gas chromatography; UV-visible and atomic absorption spectrophotometry; adsorption; filtration; ion exchange; gas transfer; sedimentation; characterization of reactor mixing regimes; coagulation.

CEE 758 Environmental Engineering Processes Laboratory II
Spring. 2 credits. Prerequisite: CEE 651 and concurrent enrollment in CEE 756. J. M. Gossett.
Laboratory studies of microbiological phenomena and environmental engineering processes. Topics include microscopy; biochemical and chemical oxygen demand; biological treatability studies; enumeration of bacteria.

CEE 759 Special Topics in Environmental Engineering
On demand. 1–6 credits. Staff.
Supervised study in special topics not covered in formal courses.

CEE 850 Thesis—Environmental Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Transportation

CEE 361 Introduction to Transportation Engineering
Spring; usually offered in summer for Engineering Co-op Program. 3 credits. A. H. Meyburg.
Introduction to technological, economic, and social aspects of transportation. Emphasis on design and functioning of transportation systems and their components. Supply-demand interactions; system planning, design, and management; traffic flow and control intersection and network analysis. Institutional and energy issues; environmental impacts.

CEE 462 Highway Engineering (also ABEN 491)
Fall. 3 credits. Prerequisites: fluid mechanics (may be taken concurrently) and junior standing in engineering. L. H. Irwin.
For description, see ABEN 491.

CEE 463 Transportation and Information Technology
Fall. 3 credits. L. Nozick.
Improvements in the utilization of existing facilities has become an important objective in transportation planning. This course examines the role of computer and telecommunications technologies to achieve these improvements. Specific attention is focused on the development of analyses to evaluate the benefits of inclusion of these technologies in transportation systems.

CEE 664 Transportation Systems Design
Spring. 3 credits. Prerequisite: CEE 361. F. L. Bennett.
Advanced techniques for physical and operational design of transportation systems, including analytical modeling techniques underlying design criteria. Evaluation of alternative designs. Management and operating policies, including investment strategies. Facility location decisions, networks, and passenger and freight terminals.

CEE 762 Transportation Research
On demand. 1–6 credits. Staff.
In-depth investigation of a particular transportation planning or engineering problem mutually agreed upon between the student and one or more faculty members.

CEE 764 Special Topics in Transportation
On demand. 1–6 credits. Staff.
Advanced subject matter not covered in depth in other regular courses.

CEE 860 Thesis—Transportation Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Structural Engineering

See also CEE 116, CEE 241, CEE 304, and CEE 595.

CEE 371 Structural Behavior
Spring. 4 credits. Prerequisite: ENGRD 202. Staff.
Fundamental concepts of structural engineering: behavior, analysis, and design. Loads, structural materials, structural form, statically determinate analysis, approximate analysis of indeterminate systems. Use of interactive graphical analysis programs. Fundamentals of behavior of steel and concrete members. Introduction to limit states design.

CEE 372 Structural Analysis
Fall; usually offered in summer for Engineering Co-op Program. 4 credits. Prerequisite: CEE 371. J. Abel.
Fundamentals of statically indeterminate structures. Moment-area and virtual-work methods of displacement computation. Matrix flexibility and stiffness methods. Moment distribution analysis. Influence lines. Computer applications to practical structures. The art of structural modeling for analysis and design. Role and limitations of analysis in design.

CEE 473 Design of Concrete Structures
Fall. 4 credits. Prerequisites: CEE 372 or permission of instructor. K. Hover.
Behavior and design of reinforced concrete and prestressed concrete structures. Design project.

CEE 474 Design of Steel Structures
Spring. 4 credits. Prerequisite: CEE 372 or permission of instructor. T. Peköz.
Behavior and design of steel members, connections, and structures. Discussion of structural systems for buildings and bridges.

CEE 476 Civil Engineering Materials
Spring. 4 credits. Prerequisites: ENGRD 202, ENGRD 261, PHYS 214 and CEE 371 (CEE 371 may be taken concurrently). P. Petrina.
Mechanical properties of concrete, metals, masonry, plastics, wood, and other structural materials. Stress-strain behavior and failure criteria. Nondestructive and destructive testing techniques for the evaluation of structures and the quality control of materials. Laboratory experiments.

CEE 672 Fundamentals of Structural Mechanics
Fall. 3 credits. M. D. Grigoriu.
Theory of elasticity, energy principles, plate flexure, failure theories for structural design, beams on elastic foundation, finite-difference method, plate theory, introduction to finite-element method.

CEE 673 Advanced Structural Analysis
Fall. 3 credits. Prerequisites: CEE 372 and computer programming. G. G. Deierlein.
Matrix analysis of structures, computer programming of displacement (stiffness) method, use of interactive graphical analysis programs, solution methods, errors and accuracy, special analysis procedures, virtual work in matrix analysis, and introduction to nonlinear analysis and finite-element methods.

[CEE 675 Concrete Materials and Construction
Spring. 3 credits. Prerequisite: CEE 376 or equivalent. Offered alternate years. Not offered 1997–98. K. C. Hover.
Materials science, structural engineering, and construction technology involved in the materials aspects of the use of concrete. Cement chemistry and physics, mix design, admixtures, engineering properties, testing of fresh and hardened concrete, and the effects of construction techniques on material behavior.]

CEE 677 Stochastic Mechanics
Fall. 3 credits. Prerequisite: permission of instructor. Offered alternate years. Not offered 1998–99; offered 1997–98. M. D. Grigoriu.
Review of concepts of probability theory, random processes, and random fields. Analytical and numerical methods for reliability analysis. Methods for solution of random eigenvalue problems, equilibrium of uncertain systems and systems with random imperfections, and propagation problems in stochastic systems. Applications include stochastic finite elements, probabilistic fracture mechanics, and dynamic Daniels systems.

CEE 680 Structural Engineering Seminar
Fall, spring. 1 credit. Limited to qualified seniors and graduate students. M. Grigoriu.
Presentation of topics of current interest in the field of structures.

[CEE 770 Engineering Fracture Mechanics
Fall. 3 credits. Prerequisite: CEE 772 or permission of instructor. Offered alternate years. Offered 1998–99; not offered 1997–98. A. R. Ingraffea.
Fundamentals of fracture-mechanics theory. Energy and stress-intensity approaches to fracture. Mixed-mode fracture. Fatigue-crack propagation. Finite- and boundary-element methods in fracture mechanics. Introduction to elastic-plastic fracture mechanics. Interactive computer graphics for fracture simulation. Laboratory techniques for fracture-toughness testing of metals, concrete, and rock.]

CEE 772 Finite Element Analysis for Mechanical, Structural, and Aerospace Applications (also T&AM 666 and M&AE 680)
Spring. 3 credits. Prerequisite: T&AM 663.
For description, see M&AE 680.

CEE 774 Advanced Concrete Structures I
Fall. 3 credits. Prerequisite: undergrad course in concrete structures. S. L. Billington.
Role of material properties in structural performance; design code philosophies; behavior and design of reinforced and prestressed concrete flexural sections; deflection prediction and control for RC and PC structures including load balancing for PC structures; continuity effects; serviceability issues; behavior and design of RC and PC slab systems; plastic truss (strut-and-tie) approach for torsion and shear; building framing systems.

[CEE 775 Advanced Concrete Structures II
Spring. 3 credits. Prerequisite: CEE 774 or equivalent. Not offered 1997–98.
Structural walls; extension of plastic truss approach to frame connections, corbels, brackets, and deep beams; anchorage region behavior in PC beams; slender columns and biaxial bending; ductility and its enhancement for resisting severe loadings; composite construction; prestress loss calculations; strip method for design of slabs with unusual geometry; bridges and other structures; control of human error in design and construction.]

CEE 776 Advanced Design of Metal Structures
Fall. 3 credits. Prerequisite: CEE 374 or equivalent. T. Pekoz.
Preliminary design of structural systems. Design of members and connections. Behavior and computer-aided design of building frames. Design of composite members.

[CEE 777 Advanced Behavior of Metal Structures
Spring. 3 credits. Prerequisite: CEE 374 or equivalent. Offered 1998–99; not offered 1997–98. T. Peköz.
Analysis of elastic and inelastic stability. Behavior and design of hot-rolled and cold-rolled steel and aluminum members, elements, and frames. Critical review of design specifications.]

CEE 779 Structural Dynamics and Earthquake Engineering
Spring. 3 credits. M. D. Grigoriu.
Modal analysis, numerical methods, and frequency-domain analysis. Introduction to earthquake-resistant design.

CEE 783 Civil and Environmental Engineering Materials Project
On demand. 1–3 credits. K. C. Hover.
Individual projects or reading and study assignments involving engineering materials.

CEE 785 Research in Structural Engineering
On demand. 1–6 credits. Staff.
Pursuit of a branch of structural engineering beyond what is covered in regular courses. Theoretical or experimental investigation of suitable problems.

CEE 786 Special Topics in Structural Engineering
On demand. 1–6 credits. Staff.
Individually supervised study or independent design or research in specialized topics not covered in regular courses. Occasional offering of such special courses as Shell Theory and Design, and Advanced Topics in Finite Element Analysis.

CEE 880 Thesis—Structural Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Staff.
A thesis research topic is selected by the student with the advice of the faculty member in charge and is pursued either independently or in conjunction with others working on the same topic.

Engineering Management

See also CEE 323 and CEE 463.

CEE 590 Project Management
Fall. 3 credits. Prerequisite: permission of instructor. M. A. Turnquist and F. J. Wayno.
An introduction to the work and skills of management, especially for the management of projects. Planning, organizing, communicating, scheduling, controlling, and correcting will be covered in combination of lectures, readings, outside assignments, and in-class role-playing exercises.

CEE 591 Engineering Management Project
Fall. 3 credits. Prerequisite: permission of instructor. Staff.
An intensive evaluation of the management aspects of a major engineering project or system. Most students will work on a large group project in the area of project management, but students may also work singly or in small groups on an engineering management topic of special interest to them.

CEE 592 Engineering Management Project
Spring. 3 credits. Prerequisite: permission of instructor. Staff.
A continuation of CEE 591.

CEE 593 Engineering Management Methods I: Data, Information, and Modeling
Fall. 3 credits. Prerequisites: OR&IE 320 and OR&IE 270 or CEE 304 or equivalent. Staff.
Methods for managing data and transforming data into information. Modeling as a means to synthesize information into knowledge that can form the basis for decisions and actions. Application of statistical methods and optimization to managerial problems in project scheduling, quality control, forecasting, and resource allocation.

CEE 594 Engineering Management Methods II: Managing Uncertain Systems
Spring. 3 credits. Prerequisite: CEE 593 or permission of instructor. L. K. Nozick.
Modeling and managing systems in which uncertainty is a major determinant of system behavior. Systems which are subject to breakdown, deterioration and queuing. Simulation as a tool for analyzing uncertain systems. Projects and case studies to illustrate application of the methods.

CEE 595 Construction Planning and Operations
Fall. 3 credits. F. L. Bennett.
A course on the fundamentals of construction planning: organization of the worksite, construction planning, scheduling, and cost estimating, bidding, temporary structures, applications of computer methods, and the relationships among owners, designers, contractors, suppliers, and developers.

CEE 597 Risk Analysis and Management
Spring. 3 credits. Prerequisite: CEE 304 or OR&IE 270 or equivalent. J. R. Stedinger.
Course develops a working knowledge of risk terminology and reliability engineering, analytic tools used to analyze environmental and technological risks, and social and psychological risk issues. Discussions address life risks in the U.S., transportation risks, waste incineration, air pollution modeling, public health, regulatory policy, risk communication, and risk management.

CEE 692 Special Topics in Engineering Management
On demand. 1–6 credits. Staff.
Individually supervised study of one or more specialized topics not covered in regular courses.

CEE 694 Research in Engineering Management
On demand. 1–6 credits. Staff.
The student may select an area of investigation in engineering management. Results should be submitted to the instructor in charge in the form of a research report.

COMPUTER SCIENCE

The Department of Computer Science is part of both the College of Arts and Sciences and the College of Engineering.

COM S 099 Fundamental Programming Concepts
Fall, summer. 2 credits. No prerequisites. S-U grades only. Credit cannot be applied toward the Engineering degree.
This course is designed for students who intend to take COM S 100 but are not adequately prepared for that course. Basic programming concepts and problem analysis are studied. The programming language used is Java. Students with previous programming experience should not take this course.

COM S 100 Introduction to Computer Programming
Fall, spring, summer. 4 credits.
An introduction to elementary computer programming concepts. Emphasis is on techniques of problem analysis and the development of algorithms and programs. The subject of the course is programming, not a particular programming language. The principal programming language is Java. COM S 100 also includes a brief introduction to Matlab. The course does not presume previous programming experience. Programming assignments are tested and run on interactive, stand-alone microcomputers. During the fall semester, two versions of COM S 100 are available as described below.

COM S 100a Introduction to Computer Programming
Standard version of COM S 100. No college-level mathematics is assumed. Register for COM S 100.

COM S 100b Introduction to Computer Programming
Prerequisite: MATH 111, 191 or equivalent. Offered fall only.
Alternative version of COM S 100, emphasizing examples and applications involving continuous mathematics, including trigonometry and calculus. Register for COM S 100. COM S 100b is not always available at all COM S 100 lecture hours.

COM S 101 Introduction to Cognitive Science (also COGST 101, LING 170, and PSYCH 102)
Fall. 3 credits.
This course surveys the study of how the mind/brain works. We will examine how intelligent information processing can arise from biological and artificial systems. The course draws primarily from five disciplines that make major contributions to cognitive science: philosophy, psychology, neuroscience, linguistics, and computer science. The first part of the course will introduce the roles played by these disciplines in cognitive science. The second part of the course will focus on how each of these disciplines contributes to the study of five topics in cognitive science: language, categorization, memory, vision, and action.

COM S 113 Introduction to C
Fall, spring. 1 credit. Weeks 5–8. Prerequisite: COM S 100 or equivalent programming experience. Credit is granted for both COM S 113 and 213 only if 113 is taken first. S-U grades only.
A brief introduction to the C programming language and standard libraries. Unix accounts will be made available for students wishing to use that system for projects, but familiarity with Unix is not required. (Projects may be done using any modern implementation of C). COM S 213 (C++ Programming) includes much of the material covered in 113. Students planning to take COM S 213 normally do not need to take 113.

COM S 114 Unix Tools
Fall, spring. 1 credit. Weeks 1–4. Prerequisite: COM S 100 or equivalent programming experience. S-U grades only.
An introduction to Unix, including shell commands, emacs, the file system, and software tools like grep, find, make, awk, and perl. Knowledge of some programming language like Java, C, C++, Pascal, or Fortran is expected, but projects will not assume expertise in any particular language.

COM S 130 Creating Web Documents
Fall. 3 credits.
Interactive on-line media such as the World Wide Web are revolutionizing the way we communicate. This course introduces students with little or no computer background to tools and techniques for creating interactive documents. Topics covered will include HTML authoring, scripting languages, interaction techniques, data mining, and incorporating sound, video, and images in documents.

COM S 211 Computers and Programming (also ENGRD 211)
Fall, spring, summer. 3 credits. Credit will not be granted for both ENGRD/COM S 211 and 212. Prerequisite: COM S 100 or equivalent programming experience.
Intermediate programming in a high-level language and introduction to computer science. Topics include program structure and organization, modules (classes), program development, proofs of program correctness, recursion, data structures and types (lists, stacks, queues, trees), object-oriented and functional programming, and analysis of algorithms. Java is the principal programming language.

COM S 212 Structure and Interpretation of Computer Programs (also ENGRD 212)
Fall, spring. 4 credits. Credit will not be granted for both ENGRD/COM S 211 and 212. Prerequisite: COM S 100 or equivalent programming experience.
A challenging introduction to programming languages and computer science that emphasizes alternative modes of algorithmic expression. Topics include recursive and

higher-order procedures, performance analysis of algorithms, proofs of program correctness, probabilistic algorithms, symbolic hierarchical data, abstract data types, polymorphic functions, object-oriented programming, infinite data types, simulation, and the interpretation of programs.

ENGRD/COM S 212 covers a wide range of topics in computer science and programming using advanced functional and object-oriented programming languages. ENGRD/COM S 211 focuses on strengthening programming skills in a more conventional programming language (Java), while still introducing important topics in computing. Either course is a suitable prerequisite for further study in the field. Appropriate transfers between ENGRD/COM S 211 and 212 (in either direction) are encouraged during the first few weeks of the semester.

COM S 213 C++ Programming
Fall, spring. 2 credits. Prerequisite: COM S 211 or 212 or equivalent programming experience. Students who plan to take COM S 113 and 213 must take 113 first. S-U grades only.
An intermediate-level introduction to the C++ programming language and the C/C++ standard libraries. Topics include basic statements, declarations, and types; stream I/O; user defined classes and types; derived classes, inheritance, and object-oriented programming; exceptions and templates. Recommended for students who plan to take advanced courses in computer science that require familiarity with C++ or C. Students planning to take COM S 213 normally do not need to take COM S 113; 213 includes most of the material taught in 113.

COM S 222 Introduction to Scientific Computation (also ENGRD 222)
Spring, summer. 3 credits. Prerequisites: COM S 100 and (MATH 222 or MATH 294).
An introduction to elementary numerical analysis and scientific computation. Topics include interpolation, quadrature, linear and nonlinear equation solving, least-squares fitting, and ordinary differential equations. The Matlab computing environment is used. Vectorization, efficiency, reliability, and stability are stressed. Special lectures on parallel computation.

COM S 280 Discrete Structures
Fall, spring. 4 credits. Prerequisite: COM S 211 or 212 or permission of instructor.
Covers mathematical aspects of programming and computing. Topics will be chosen from the following: mathematical induction; logical proof; propositional and predicate calculus; combinatorics and discrete mathematics covering manipulation of sums, recurrence relations, and generating-function techniques; basic number theory; sets, functions, and relations; partially ordered sets; graphs, and algebraic structures.

COM S 314 Introduction to Digital Systems and Computer Organization
Fall, spring. 4 credits. Prerequisite: COM S 211 or 212, or equivalent.
Introduction to computer organization. Topics include representation of information, machine and assembly languages, processor organization, input/output devices, memory hierarchies, combinatorial and sequential circuits, data path and control unit design, and RISC pipelining. The course features several major projects, including a full RISC processor design.

COM S 381 Introduction to Theory of Computing
Fall, summer. 4 credits. Prerequisite: COM S 280 or permission of instructor. Credit will not be granted for both COM S 381 and COM S 481. Corrective transfers between COM S 381 and COM S 481 (in either direction) are encouraged during the first few weeks of instruction.
An introduction to modern theory of computing: automata theory, formal languages, and effective computability.

COM S 400 The Science of Programming
Spring. 4 credits. Prerequisite: COM S 280 or equivalent. Not offered every year; next offered spring 1998.
The practical development of correct programs based on the conscious application of principles that are derived from a mathematical notion of program correctness. Besides dealing with conventional sequential programs, the course covers implementations of abstract data types and contains an introduction to problems with concurrency. Issues in programming-language design that arise from program correctness are discussed. Programs are written but not run on a computer.

COM S 410 Data Structures
Fall, spring, summer. 4 credits. Prerequisite: COM S 280 or permission of instructor.
Lists, trees, graphs, arrays, and other forms of data structure and their implementation. Relationship between language and data structure, emphasizing abstract data types. Dynamic storage allocation and memory management. Detailed study of searching and sorting methods. Analysis to determine the more efficient algorithm in a given situation.

[COM S 411 Programming Languages and Logics
Fall. 4 credits. Prerequisite: COM S 410 or permission of instructor. Not offered every year; semester to be announced.
The major concepts of programming languages, with emphasis on synthesis and interpretation. Language-based programming methodologies, including object-oriented, functional, and logic programming. Design and criticism of programming languages. Type theory and typed lambda-calculus. Exercises in several unusual programming languages.]

COM S 412 Introduction to Compilers and Translators
Spring. 3 credits. Prerequisites: COM S 314, 381, 410. Corequisite: COM S 413.
Overview of the internal structure of modern compilers, with emphasis on implementation techniques. Topics covered include lexical scanning, simple parsing techniques, symbol-table manipulation, type-checking routines, code generation, and simple optimizations. The course entails a compiler implementation project.

COM S 413 Practicum in Compilers and Translators
Spring. 2 credits. Prerequisites: COM S 314, 381, 410. Corequisite: COM S 412.
A compiler implementation project related to COMS 412.

COM S 414 Systems Programming and Operating Systems
Fall, summer. 3 credits. Prerequisite: COM S 314 or permission of instructor.
An introduction to the logical design of systems programs, with emphasis on multiprogrammed operating systems. Topics include process synchronization, deadlock, memory management, input-output methods, information sharing, protection and security, and file systems. The impact of network and distributed computing environments on operating systems is also discussed.

COM S 415 Practicum in Operating Systems
Fall. 2 credits. Prerequisite: COM S 410. Corequisite: COM S 414.
The practical aspects of operating systems are studied through the design and implementation of an operating system kernel that supports multiprogramming, virtual memory, and various input-output devices. All the programming for the project is in a high-level language.

COM S 417 Computer Graphics and Visualization (also ARCH 374)
Spring. 3 credits. Prerequisite: COM S 211 or 212.
An introduction to the principles of interactive computer graphics and scientific visualization. Topics include surface modeling, animation, perspective transformations, hidden-line and hidden-surface algorithms, lighting models, image synthesis, and application to scientific data analysis.

COM S 418 Practicum in Computer Graphics (also ARCH 375)
Spring. 2 credits. Enrollment limited. Permission of instructor. Prerequisite: COM S 211 or 212. Recommended: COM S 314. Co-requisite: COM S 417.
Programming assignments dealing with interactive computer graphics and visualization of scientific data.

COM S 421 Numerical Analysis
Fall. 4 credits. Prerequisites: MATH 294 or equivalent, one additional mathematics course numbered 300 or above, and knowledge of programming.
Modern algorithms for systems of linear equations, systems of nonlinear equations, numerical optimization, and numerical solution of differential equations. Some discussion of methods suitable for parallel computation.

COM S 432 Introduction to Database Systems
Fall. 3 credits. Prerequisites: (ENGRD/COM S 211 or 212) and COM S 410. Recommended: COM S 213.
Introduction to modern relational database systems. Concepts covered include database design theory, query languages, storage structures, access methods, query processing and optimization.

The course primarily covers the internals of database systems, and includes an implementation project.

COM S 433 Practicum in Database Systems
Fall. 2 credits. Corequisite: COM S 432.
Students will implement a simple relational database system with coding assignments ranging from disk management to high-level query processing. This provides a thorough understanding of database system internals.

COM S 444 Distributed Systems and Algorithms

Fall. 4 credits. Pre- or co-requisite: COM S 414 or permission of instructor. Not offered every year; next offered fall 1997.

The fundamentals of distributed systems and algorithms. Topics include the problems, methodologies and paradigms necessary for understanding and designing distributed applications, with an emphasis on fault-tolerant computing. Theoretical concepts will be complemented with practical examples of their application in current distributed systems.

COM S 472 Foundations of Artificial Intelligence

Fall. 3 credits. Prerequisites: (COM S 211 or COM S 212) and COM S 280 or equivalent.

A challenging introduction to the major subareas and current research directions in artificial intelligence. Topics include knowledge representation, heuristic search, problem solving, natural-language processing, game-playing, logic and deduction, planning, and machine learning.

COM S 473 Practicum in Artificial Intelligence

Fall. 2 credits. Prerequisite: (COM S 211 or COM S 212) and COM S 280 or equivalent. Corequisite: COM S 472.

Project portion of COM S 472. Topics include Common LISP programming, representation systems, deductive retrieval, databases and frame languages, and truth-maintenance-system implementations.

COM S 481 Introduction to Theory of Computing

Fall. 4 credits. Prerequisite: COM S 280 or permission of instructor. Credit will not be granted for both COM S 381 and 481. Corrective transfers between COM S 481 and 381 (in either direction) are encouraged during the first few weeks of instruction.

A faster-moving and deeper version of COM S 381.

COM S 482 Introduction to Analysis of Algorithms

Spring, summer. 4 credits. Prerequisites: COM S 410 and either 381 or 481, or permission of instructor.

Techniques used in the creation and analysis of algorithms. Combinatorial algorithms, computational complexity, NP-completeness, and intractable problems.

COM S 486 Applied Logic (also MATH 486)

Fall or spring. 4 credits. Prerequisites: MATH 222 or 294, COM S 280 or equivalent (such as MATH 332, 432, 434, 481), and some additional course in mathematics or theoretical computer science.

Propositional and predicate logic, compactness and completeness by tableaux, natural deduction, and resolution. Equational logic. Herbrand Universes and unification. Rewrite rules and equational logic, Knuth-Bendix method and the congruence-closure algorithm and lambda-calculus reduction strategies. Topics in Prolog, LISP, ML, or Nuprl. Applications to expert systems and program verification.

COM S 490 Independent Reading and Research

Fall, spring. 1–4 credits.

Independent reading and research for undergraduates.

COM S 501 Software Engineering: Technology and Technique

Fall. 4 credits. Prerequisite: COM S 410 and knowledge of the C programming language.

An introduction to the problems of building large, reliable software systems and the methods, languages, and tools used in modern software development. Topics include software life-cycle models, software analysis and design, verification and validation, reliability, engineering ethics and professionalism. Programming topics include modularity, data abstraction, object-oriented programming, and effective use of C++. General techniques will be complemented with programming experience using industrial-strength languages and tools.

COM S 514 Distributed Systems

Fall or spring. 4 credits. Prerequisites: COM S 414 or permission of instructor.

Practical issues in designing and implementing distributed software. Topics include local and wide-area network protocols, replicated data, dynamic reconfiguration, monitoring for and reacting to failures or recoveries, distributed computation, synchronization, and techniques for expressing coarse-grained parallelism at the application level.

COM S 515 Practicum in Distributed Systems

Fall or spring. 1–2 credits. Co-requisite: COM S 514.

The practical aspects of distributed systems are studied through the design and implementation of a significant system. Students may work alone or in teams. The project varies from year to year, at the discretion of the instructor.

COM S 516 High-performance Computer Architecture

Spring. 4 credits. Prerequisite: COM S 314 required; COM S 412 or 414 highly recommended.

Introduces techniques used in high-performance computer architecture. Covers pipelining of instruction execution to superscalar, superpipelined, and speculative architectures; memory system design, including caches, operating system support in the form of naming and protection schemes; introduction to parallel architectures.

COM S 519 Engineering Computer Networks

Fall. 4 credits. Prerequisites: COM S 214, 314, and 410, or permission of instructor.

Introduction to telephone, IP, and ATM networks. Techniques for system design and protocol layers. Detailed introduction to networking protocols in the areas of multiple access, switching, scheduling, routing, naming and addressing, error control, flow control, and traffic management. Overview of important protocols in the Internet and telephone networks. Protocol implementation techniques. The course is project-oriented and requires familiarity with C programming.

[COM S 522 Software Tools for Computational Science

Spring. 4 credits. Prerequisites: a numerical analysis course such as (COM S 222 or 421) or PHYS 480; willingness to work in Matlab and C or Fortran; interest in mathematics and the natural sciences. Not offered every year; semester to be announced.

Hands-on exploration of some of the principal software tools of computational science in use today. The course is divided into seven two-week segments: problem-solving environments, symbolic computing, software libraries, visualization, parallel computing, program transformations, and Web-based computing. Scientific themes are emphasized throughout, so that the ideas explored in the course may be of lasting value even if some of the particular tools used are destined to be short-lived.]

COM S 572 Introduction to Automated Reasoning

Spring. 3 credits.

This course teaches the use of a modern theorem proving system such as Nuprl or PVS or HOL. It covers the underlying logic as well as system operation and style of use. Assignments and projects involve the use of these systems on typical problems in software or hardware engineering and on the issues arising in creating a database of formalized mathematics.

COM S 601 System Concepts

Fall. 3 credits. Prerequisites: Open to students enrolled in the COM S Ph.D. program.

This course teaches broadly applicable principles of computing system design and analysis. For example, the principle of locality of reference used in caching, virtual memory, and network service hints. Such broadly applicable abstractions will be discussed along with their implementations in a variety of settings. Case studies from the systems literature will be employed throughout.

COM S 611 Advanced Programming Languages

Fall. 4 credits. Graduate standing or permission of instructor.

A study of programming paradigms: functional, imperative, concurrent and logic programming. Models of programming languages, including the lambda calculus. Type systems, polymorphism, modules, and other object-oriented constructs. Program transformations, programming logic, and applications to programming methodology.

COM S 612 Compiler Design for High-Performance Architectures

Spring. 4 credits. Prerequisites: COM S 314 and 412 or permission of instructor.

Compiler design for pipelined and parallel architectures. Program analysis: data and control dependencies, dataflow analysis, efficient solution of dataflow equations, dependence tests, solution of Diophantine equations. Architecture and code generation for instruction-level parallel (ILP) processors: pipelined, VLIW and superscalar architectures, code reorganization and software pipelining. Architecture and code generation for multiprocessors: shared- and distributed-memory architectures, latency tolerance and avoidance, loop transformations to enhance parallelism and locality of reference.

COM S 613 Concurrent Programming

Spring. 4 credits. Prerequisite: COM S 414 or permission of instructor. Not offered every year; semester to be announced.

Advanced techniques in, and models of, concurrent systems. Synchronization of concurrent processes; parallel programming languages; deadlock; verification.

COM S 614 Advanced Systems
Spring. 4 credits. Prerequisite: COM S 414 or permission of instructor.
An advanced course in systems, emphasizing contemporary research in distributed systems. Topics may include communication mechanisms, consistency in distributed systems, fault-tolerance, knowledge and knowledge-based protocols, performance, scheduling, concurrency control, and authentication and security issues.

COM S 618 Principles of Distributed Computing Message-Passing
Fall. 4 credits. Prerequisite: COM S 444 or permission of instructor.
This course focuses on research in message-passing distributed computing. It covers the fundamental problems and presents some of the latest results and open questions in message-passing systems. Problems will be viewed from a theoretical standpoint with an emphasis on precise specifications, proofs of correctness, upper and lower bounds on various complexity measures and impossibility results.

COM S 621 Matrix Computations
Fall. 4 credits. Prerequisites: MATH 411 and 431 or permission of instructor.
Stable and efficient algorithms for linear equations, least squares, and eigenvalue problems. Direct and iterative methods are considered. The Matlab system is used extensively.

[COM S 622 Numerical Optimization and Nonlinear Algebraic Equations
Spring. 4 credits. Prerequisite: COM S 621. Offered in odd-numbered years. Not offered 1997–98.
Modern algorithms for the numerical solution of multidimensional optimization problems and simultaneous nonlinear algebraic equations. Emphasis is on efficient, stable, and reliable numerical techniques with strong global convergence properties: quasi-Newton methods, modified Newton algorithms, and trust-region procedures. Special topics may include large-scale optimization, quadratic programming, and numerical approximation.]

COM S 624 Numerical Solution of Differential Equations
Spring. 4 credits. Previous exposure to numerical analysis, mathematical analysis including Fourier methods, and differential equations. Offered in even-numbered years.
Finite difference and spectral methods for the solution of differential equations. A fast-moving course that begins with a three-week survey of numerical methods for ODEs, then moves on to Fourier analysis and methods for PDEs, especially parabolic and hyperbolic equations. Other topics covered include numerical stability, the treatment of boundary conditions, and multigrid methods. This course combines theory and programming (in Matlab), emphasizing fundamental principles more than applications.

COM S 631 Multimedia Systems
Fall. 4 credits. Prerequisites: COM S 414 or permission of instructor.
Hardware and software issues involved in computer manipulation of audio, video, and images. Topics include media capture, representation, compression, editing, processing, storage, and transportation. Special emphasis on the processing of digital video, including algorithms for special effects and automatic extraction of content, and applications of parallel architectures to video processing.

COM S 632 Advanced Database Systems
Spring. 4 credits. Prerequisite: COM S 432–433 or permission of instructor.
A variety of advanced issues ranging from transaction management to query processing to data mining. Extensive paper reading and discussion. Development of a term project with research content.

COM S 664 Machine Vision
Spring. 4 credits. Prerequisites: undergraduate-level understanding of algorithms and Math 221 or equivalent.
An introduction to computer vision. The following topics will be covered: edge detection, image segmentation, stereopsis, motion and optical flow, shape reconstruction, shape representations and extracting shapes from images, model-based recognition. Students will be required to implement several of the algorithms covered in the course and evaluate them on both synthetic and real images.

COM S 671 Introduction to Automated Reasoning
Fall. 4 credits. Prerequisite: graduate standing and COM S 611 or permission of instructor.
Topics in modern logic needed to understand and use automated reasoning systems such as HOL, Nuprl, and PVS. Special emphasis on type theory and logic and on tactic-oriented theorem proving.

COM S 674 Natural Language Processing
Spring. 4 credits. Prerequisites: COM S 472 or permission of instructor. Not offered every year; semester to be announced.
This course presents an introduction to natural language understanding, a subfield of artificial intelligence whose primary concern is the computational study of language use. The course will cover all aspects of natural language processing including semantic interpretation, syntactic analysis, discourse processing, text summarization, natural language generation, language acquisition, knowledge acquisition, memory models, and statistical methods of ambiguity resolution. The course emphasizes computational modeling and the realization of theories of language processing in computer programs.

[COM S 676 Reasoning about Knowledge
Fall. 4 credits. Prerequisites: mathematical maturity and an acquaintance with propositional logic. Not offered every year; next offered fall 1998.
Knowledge plays a crucial role in distributed systems, game theory, and artificial intelligence. Material examines formalizing reasoning about knowledge and the extent to which knowledge is applicable to those areas. Issues: common knowledge, knowledge-based programs, applying knowledge to analyzing distributed systems, attainable states of knowledge, and modeling resource-bounded reasoning. Connections to game theory.]

COM S 677 Reasoning about Uncertainty
Fall. 4 credits. Prerequisites: mathematical maturity and an acquaintance with propositional logic. Not offered every year; next offered fall 1997.
Examines formalizing reasoning about and representing uncertainty, using formal logical approaches as a basis. Topics: logics of probability, combining knowledge and probability, probability and adversaries, conditional logics of normality, Bayesian networks, qualitative approaches to uncertainty, going from statistical information to degrees of belief. Connections to game theory.

COM S 681 Analysis of Algorithms
Fall. 4 credits. Prerequisite: COM S 381 or 481, or permission of instructor.
Methodology for developing efficient algorithms, primarily for graph theoretic problems. Understanding of the inherent complexity of natural problems via polynomial-time algorithms, randomized algorithms, NP-completeness, randomized reducibilities. Additional topics such as parallel algorithms and efficient data structures.

COM S 682 Theory of Computing
Spring. 4 credits. Prerequisite: (COM S 381 or 481) and (COM S 482 or COM S 681), or permission of instructor.
Advanced treatment of theory of computation, computational-complexity theory, and other topics in computing theory.

COM S 709 Computer Science Colloquium
Fall, spring. 1 credit. S-U grades only. For staff, visitors, and graduate students interested in computer science.
A weekly meeting for the discussion and study of important topics in the field.

COM S 713 Seminar in Systems and Methodology
Fall, spring. 4 credits. Prerequisites: a graduate course employing formal reasoning such as COM S 600, 611, 613, 615, 671, a logic course, or permission of instructor. Not offered every year; semester to be announced.
Discussion of contemporary issues in the design and analysis of computing systems. Emphasis on the proper use of rigor, models, and formalism.

COM S 715 Seminar in Programming Refinement Logics
Fall, spring. 4 credits. Prerequisite: permission of instructor.
Topics in programming logics, possibly including type theory, constructive logic, decision procedures, heuristic methods, extraction of code from proofs, and the design of proof-development and problem-solving systems.

COM S 717 Topics in Parallel Architectures
Fall. 4 credits. Prerequisite: COM S 612 or permission of instructor. Not offered every year; semester to be announced.
Covers topics in parallel computers. Material includes: architectures of parallel computers, parallelizing compilers, operating systems for parallel computers, and languages (functional and logic-programming languages) designed for parallel computation.

COM S 719 Seminar in Programming Languages
Fall, spring. 4 credits. Prerequisite: COM S 611 or permission of instructor. S-U grades only.

COM S 722 Topics in Numerical Analysis
Fall, spring. 4 credits. Prerequisite: COM S 621 or 622 or permission of instructor. Not offered every year; semester to be announced.
Topics are chosen at instructor's discretion.

COM S 729 Seminar in Numerical Analysis/ACRI
Fall, spring. 1–4 credits (to be arranged). Prerequisite: permission of instructor. S-U grades only.

COM S 754 Seminar in Work-in-Progress Distributed Systems
Fall, spring. 1 credit.

COM S 773/774 Proseminar in Cognitive Studies I & II (also COGST, PHIL, LING, and PSY 773/774)
Fall and spring. 2 credits.
This is a year-long lecture-and-discussion course that is intended to provide graduate students with an interdisciplinary introduction to the study of knowledge, its presentation, acquisition, and use. Topics may include the psychology of perception and cognition; the philosophy of mind, language, and knowledge; the phonology, syntax, and semantics of natural language; computational approaches to natural language processing, vision, and reasoning; parallel distributed processing; and neuropsychology.

COM S 775 Seminar in Natural Language Understanding
Fall, spring. 2 credits.
Informal weekly seminar in which current topics in natural language understanding and computational linguistics are discussed.

COM S 789 Seminar in Theory of Algorithms and Computing
Fall, spring. 2–4 credits. Prerequisite: permission of instructor. S-U grades only.

COM S 790 Special Investigations in Computer Science
Fall, spring. Prerequisite: permission of a computer science adviser. Letter grade only.
Independent research or Master of Engineering project.

COM S 890 Special Investigations in Computer Science
Fall, spring. Prerequisite: permission of a computer science adviser. S-U grades only.
Master of Science degree research.

COM S 990 Special Investigations in Computer Science
Fall, spring. Prerequisite: permission of a computer science adviser. S-U grades only. Doctoral research.

ELECTRICAL ENGINEERING

ELE E 210 Introduction to Electrical Systems (also ENGRD 210)
Fall, spring. 3 credits. Corequisites: MATH 293 and PHYS 213.
For description, see ENGRD 210.

ELE E 215 Electrical Systems Laboratory
Spring. 3 credits. Co-requisite: ENGRD 210. Letter grade only.
Basic electric and electronic instrumentation. Measurements and design involving circuits with both active and passive elements; characterization of semiconductor devices. Introduction of the personal computer as a laboratory aid. Technical report writing and communication skills.

ELE E 232 Practicum in Digital Systems
Fall and spring. 1 credit. Pre- or co-requisite: ENGRD 231.
Laboratory projects in the design and implementation of combinational and sequential digital systems for computations, communications, and information distribution.

ELE E 250 Technology in Society (also ENGRG 250 and S&TS 250)
Fall. 3 credits. Approved for humanities distribution.
For description, see ENGRG 250.

ELE E 291–292 Sophomore Electrical Engineering Project
291, fall; 292, spring. 1–8 credits. Limited to sophomores in Engineering.
Individual study, analysis, and, usually, experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing the project. An engineering report on the project is required. Students must make individual arrangements with a faculty sponsor prior to registration.

ELE E 298 Inventing the Power and Information Society (also ENGRG 298)
Spring. 3 credits. Approved for humanities distribution.
For description, see ENGRG 298.

ELE E 301 Electrical Signals and Systems I
Fall. 3 credits. Prerequisites: a grade of at least C+ in ENGRD 210 and C in MATH 293 and 294.
Continuous- and discrete-time signals and systems; Fourier series and transforms; bilateral Laplace and z transforms; convolution; FFTs and DFTs; applications to modulation, filtering, and sampling.

ELE E 302 Introduction to Digital Signal Processing
Spring. 4 credits. Prerequisite: ELE E 301.
The use of digital technology to store, change, and create sounds and pictures, digital signal processing (DSP), is one of the most significant technological developments in the last half-century. This course presents the mathematical concepts necessary to develop a clear and intuitive understanding of the key concepts in DSP. These include sampling, quantization, Fourier analysis, and digital filtering.

ELE E 303 Electromagnetic Fields and Waves
Fall. 3 credits. Prerequisites: grades of C or better in PHYS 213, 214 and MATH 294.
Maxwell's equations in integral and differential form; wave equation; plane electromagnetic waves; phase and group velocities; Poynting's theorem, complex dielectric constant; dispersive media; wave reflection and transmission; dielectric and conducting interfaces; guided waves on transmission lines; transient pulse propagation; elementary dipole antenna.

ELE E 306 Fundamentals of Quantum and Solid-State Electronics
Spring. 4 credits. Prerequisites: PHYS 214 and MATH 294.
Introductory quantum mechanics and solid-state physics necessary for modern solid-state electronic devices. Topics include the formalism and methods of quantum mechanics, the hydrogen atom, the structure of simple solids, energy bands, Fermi-Dirac statistics, and the basic physics of semiconductors. Applications include quantum wells and the p-n junction.

ELE E 308 Fundamentals of Computer Engineering
Spring. 4 credits. Prerequisite: ENGRD 231, ELE E 232 and ENGRD/COM S 211.
This course provides a fundamental understanding of computer systems, including their integration into embedded systems. Topics covered include assembly language programming, machine code generated by compilers, high-level language data structures, computer organization, CISC and RISC computer architectures, floating point arithmetic, I/O, and memory hierarchy.

ELE E 310 Introduction to Probability and Random Signals
Spring. 4 credits. Prerequisite: MATH 294. This course may be used in place of ENGRD 270 to help satisfy the engineering distribution requirement. It can then also meet a field breadth requirement if 3 additional credits of field approved or out-of-field elective are taken.
Introduction to the theory of probability as a basis for modeling random phenomena and signals, calculating the response of systems, and making estimates, inferences, and decisions in the presence of chance and uncertainty. Applications will be given in such areas as communications, and device modeling, probability, characteristic functions; nonlinear transformations of data; expectation, correlation; and the central limit theorem.

ELE E 311 Electrical Engineering Honors Seminar
Spring. 2 credits variable.
Students registered for this course are required to attend all of the colloquia lectures. Concise summary papers, (maximum of three pages) are required. Honors students who take the seminar for letter grade are required to write two summary papers. Those non-honors students who take the seminar pass/fail are only required to write one summary paper. Each paper may review any the topic presented during the term.

ELE E 315 Electronic Circuit Design
Fall. 4 credits. Prerequisites ELE E 210 and ELE E 215.
Design of electronic circuits for computers, signal processing, communication, microelectronics, optoelectronics, measurements and control. Analog, digital, and mixed signals. Design of building blocks and design with building blocks. Methodology based on estimation, hand calculation, and circuit simulation. PC based on data acquisition, analysis and simulation. Weekly laboratory sessions.

ELE E 360 Ethical Issues in Engineering (also ENGRG 360 and S&TS 360)
Spring. 3 credits. A social science elective for engineering students.
For description, see ENGRG 360.

ELE E 391–392 Junior Electrical Engineering Project
391, fall; 392, spring. 1–8 credits. Limited to juniors in Engineering.
Individual study, analysis, and, usually, experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty

member directing the project. An engineering report on the project is required. Students must make individual arrangements with a faculty sponsor prior to registration.

ELE E 411 Random Signals in Communications and Signal Processing
Fall. 3 credits. Prerequisite: ELE E 301 and 310 or equivalent.
Introduction to models for random signals in discrete and continuous time; Markov chains, Poisson process, queuing processes, power spectral densities, Gaussian random process. Response of linear systems to random signals. Elements of estimation and inference as they arise in communications and digital signal processing systems.

ELE E 416 Global Position System Theory and Design
Spring. 4 credits. Prerequisites: ELE E 301 and ELE E 303 or permission of the instructor. 4 design credits.
A laboratory course using the Global Positioning System as a model for examining space-based engineering systems. The course consists of lectures, laboratories, and a design project. The laboratory is based on a GPS engine development system and covers the navigation solution, receiver design and function, and differential GPS.

ELE E 423 Computer Methods in Digital Signal Processing
Fall. 4 credits. Prerequisite: ELE E 302. Satisfies undergraduate computer-applications requirement.
Basic computational techniques used in signal processing and communications. Fast algorithms for multidimensional transforms. Solution of structured systems of linear equations. Algorithms for linear least squares estimation problems. Influence of quantization and finite precision arithmetic on the accuracy of numerical methods. Influence of the architecture of modern microprocessors on the design and performance of numerical algorithms.

ELE E 425 Digital Signal Processing
Fall. 4 credits. Prerequisite: ELE E 301 and ELE E 302.
Fundamentals of signal analysis, review of Fourier, Laplace, and Z transforms. Sampling and reconstruction. Discrete Fourier transform properties and computation (FFT). Digital filter design; the approximation problem for FIR and IIR filters, perception, statistical modeling of images, image transforms. Compression, enhancement, restoration analysis.

ELE E 426 Applications of Signal Processing
Spring. 3 or 4 credits. Prerequisite: ELE E 425.
Applications of signal processing, including signal analysis, filtering, and signal synthesis. The course is laboratory oriented, emphasizing individual student projects. Design is done with signal-processing hardware and by computer simulation. Topics include filter design, spectral analysis, speech coding, speech processing, digital recording, adaptive noise cancellation, and digital signal synthesis.

ELE E 430 Lasers and Optical Electronics
Fall. 4 credits with lab; may be taken for 3 credits without lab. Prerequisite: ELE E 303 or equivalent.
An introduction to the operation of lasers and devices based nonlinear and nonlinear optics. Material covered includes diffraction-limited optics, Gaussian and beams, optical resonators, interaction of radiation with matter, physics of laser operation, laser design. Applications of coherent radiation to nonlinear optics, communication, and research will be discussed.

ELE E 433 Microwave Integrated Circuits
Fall. 4 credits; may be taken for 3 credits without laboratory. Prerequisites: ELE E 303 and ELE E 306.
An introduction to the design and testing of high-speed circuits (frequencies above 1 GHz). Topics include: computer-aided design, automated microwave measurement techniques, optoelectronic applications, and GaAs monolithic microwave integrated circuits. Six two-week labs cover the basics of designing, fabricating, and testing microwave integrated circuits.

ELE E 439 VLSI Digital System Design
Fall. 4 credits. Prerequisites: ENGRD 231, ELE E 232 and EE 315. (See ELE E 539)
Custom CMOS VLSI design as seen by a system designer. Emphasis on structured design methodologies for digital VLSI systems. Topics include MOS transistors, design rules for MOS integrated circuits, implementation of common digital components, clocking disciplines for VLSI, tools for computer-aided design, system design for performance, and novel architectures for VLSI systems.

ELE E 445 Computer Networks and Telecommunications
Fall. 3 credits. Prerequisites: ELE E 308 (or COM S 314) and a course in probability.
Design, analysis, and implementation of local area networks, wide area networks, and telecommunications systems; circuit switching, packet switching; broad band switching; protocols; asynchronous transfer mode systems.

ELE E 451–452 Electric Power Systems I and II
451 fall; 452 spring. 3 credits each term. Prerequisite: ELE E 301.
The objective is to acquaint the student with modern electric power system operation and control. Aspects of the restructuring of the industry and its implications for planning and operation objectives and methods will be explored. Topics include unit commitment, economic dispatch, optimal power flow, control of generation, system security and reliability, state-estimation, analysis of system dynamics and system protection.

ELE E 453 Integrated Circuit Design
Fall. 4 credits. Prerequisites: ELE E 301 and ELE E 315 or equivalent. ELE E 457 recommended as a corequisite.
Introduction to analysis and design of digital and analog MOS and bipolar integrated circuits (IC). Computer-aided design. Common building blocks for digital and analog applications (inverters, switches, single-stage units, sources, sinks, differential pairs, active loads). Steady-state and transient analysis, frequency response and noise. Overview of common IC designs (microprocessors, memories, amplifiers).

ELE E 457 Silicon Semiconductor Electronics
Fall. 4 credits with lab. Prerequisites: ELE E 315 and ELE E 306 or equivalent.
Fundamental electronic properties of semiconductors. Energy-band diagrams, carrier transport and recombination, pn junctions, metal-semiconductor Schottky contacts, ohmic contacts, and metal-oxide-semiconductor (MOS) structures. Operation of bipolar junction transistors (BJTs) and field effect-transistors (FETs). Six two-week labs covering electrical measurements of semiconductor materials and devices.

ELE E 467 Communication Systems I
Fall. 4 credits. Prerequisites: ELE E 301 and ELE E 310. Suggested co-requisite: ELE E 411.
An introduction to analog and digital modulation and demodulation techniques. Topics include: analog signal representation and filtering; analog amplitude modulation (AM) and frequency modulation (FM); digital pulse amplitude modulation (PAM); digital transmission via carrier modulation: amplitude-shift keying (ASK), phase-shift keying (PSK), quadrature amplitude modulation (QAM); fundamentals of random processes, white Gaussian noise; effect of noise on analog modulation techniques; error probabilities for digital transmission through additive white Gaussian noise (AWGN) channels.

ELE E 468 Communication Systems II
Spring. 4 credits. Prerequisite: ELE E 467 or permission of instructor. Suggested prerequisite: ELE E 411.
Fundamentals of digital communications. Topics include: digital source coding, Huffman coding, sampling, quantization, analog source coding; optimum receivers for digital transmission through additive white Gaussian noise (AWGN) channels, matched filters; channel capacity and error control coding; digital transmission through bandlimited AWGN channels, inter-symbol interference (ISI), equalization techniques; phase-locked loops (PLL); trellis-coded modulation (TCM); spread-spectrum communication systems.

ELE E 471 Feedback Control Systems (also M&AE 478)
Fall. 4 credits. Prerequisite: ELE E 301 or permission of instructor.
Analysis techniques, performance specifications, and analog-feedback-compensation methods for single-input, single-output, linear, time-invariant systems. Laplace transforms and transfer functions are the major mathematical tools. Design techniques include root-locus and frequency response methods. Computer-aided design laboratory examines modeling and control of a computer-simulated dynamic process.

ELE E 472 Digital Control Systems
Spring. 4 credits. Prerequisite: ELE E 471 or permission of instructor.
Analysis and design of feedback control systems using digital devices to implement compensation. Z-transforms and linear algebra are the major mathematical tools. Topics include: state realizations, digitizations of analog systems, least-squares system identification, state feedback control, observers, combined observer-controller, and algebraic-control design. Assignments will consist of reports on computer-aided controller design and digitally simulated evaluation.

ELE E 475 Computer Structures

Fall. 4 credits. Prerequisites: ELE E 308 (or COM S 314), ENGRD 231 and ELE E 232 or permission of instructor.

Methods of designing digital computers and the hardware-software interface to the systems they function with. Topics include control sequencer and data path design, memory and I/O organization and interfacing, and interrupt hardware design. Laboratory groups will design and build a small digital computer. User-programmable logic devices will be employed for circuit implementation.

ELE E 476 Digital Systems Design Using Microcontrollers

Spring. 4 credits. Prerequisite: ELE E 308 or COM S 314 (ELE E 475 strongly recommended).

Design of real-time digital systems using microprocessor-based embedded controllers. Students working in pairs will design, debug, and construct several small systems that illustrate and employ the techniques of digital system design acquired in previous courses. The content focuses on the laboratory work, the lectures being used primarily for the introduction of examples, description of specific modules to be designed, and instruction in the hardware and high-level design tools to be employed. The laboratory environment is that of ELE E 475 enhanced with the addition of an integrated single-board computer based on the 80C196KB microcontroller chip. Programming is in assembly language and (optionally) C.

[ELE E 482 Plasma Processing of Electronic Materials

Spring. 3 credits. Prerequisite: ELE E 303 or its equivalent. Not offered 1997–98.

Fundamental principles that govern partially ionized, chemically reactive plasma discharges and their applications to processing electronic materials. Topics include simple models of low pressure, partially ionized plasmas, collision phenomena, diffusive processes, plasma chemistry and surface processes. Examples and their applications to electronic materials processing will be discussed in detail.]

ELE E 484 Introduction to Controlled Fusion: Principles and Technology (also NS&E 484)

Spring. 3 credits. Prerequisites: ELE E 303, or permission of instructor. Intended for seniors and graduate students. May not be offered 1997–98.

For description, see NS&E 484.

ELE E 485 Atmospheric and Ionospheric Physics (also ASTRO 485)

Fall. 3 credits. Prerequisites: Physics through 214 or equivalent, introductory chemistry, introductory differential equations.

The structure and dynamics of the middle atmosphere and the ionosphere are surveyed. Topics include energy balance and thermal structure, global circulation patterns, ionization, production and loss of charged particles, coupling of the neutral atmosphere with electric fields, charged particle transports, and observation techniques.

ELE E 486 Electromagnetic Waves and Communication

Spring. 4 credits. Prerequisite: ELE E 303.

This course is recommended for students who wish to obtain a greater understanding of E & M aspects of the fundamentals of guided waves, high data rate electronics and wireless communication. Topics to be covered will include: Vector and scalar potentials, transmission lines, waveguides, fiber optics, antenna arrays, propagation in different environments including interference and diffraction.

ELE E 487 Introduction to Antennas and Radar

Fall. 3 credits. Prerequisites: ELE E 301 and ELE E 304 (or a grade of B or better in ELE E 303).

Fundamentals of antenna theory, including gain and effective area, near and far fields, phased arrays, aperture antennas and aperture synthesis. Fundamentals of radar, including detection, tracking, Doppler shifts, sampling, range and frequency aliasing. Synthetic aperture radars and remote sensing from aircraft and satellites; over-the-horizon (OTH) radars and ionospheric propagation effects; radar astronomy techniques.

ELE E 488 RF Circuits and Systems

Spring. 3 credits. Prerequisites: ELE E 315 or equivalent. 2 design credits. Lab credit.

Basic RF circuits and applications. Receivers, transmitters, modulators, filters, detectors, transmission lines, oscillators, frequency synthesizers, low-noise amplifiers. Applications include communication systems, radio and television broadcasting, radar, radio and radar astronomy. Computer-aided circuit analysis. Five laboratory sessions.

ELE E 490 Practicum in Systems Engineering

Fall only. 3 credits. Group II Electrical Engineering Lab + 1 credit of Engineering Design. Prerequisite: ELE E 308 and ELE E 315.

Concepts involved with bringing a product to reality. You will use your creative abilities, together with your knowledge of analog and digital circuit design, microprocessor systems, and semiconductor devises, to create a simple engineered product: a micro-controller based, PWM switching light dimmer. Included will be system design concepts presented by staff from Lutron Electronics, Inc.: product cycle, product specification, including UL safety issues and new product testing, RFI and product testing. Microcontroller based design, switching electronics, switching supplies and pulse width modulation. A final team product prototype is required as are several major presentations during the semester.

ELE E 491–492 Senior Electrical Engineering Project

491, fall; 492, spring. 1–8 credits. Limited to seniors in Engineering.

Individual study, analysis, and, usually, experimental tests in connection with a special engineering problem chosen by the student after consultation with the faculty member directing the project. An engineering report on the project is required. Students must make individual arrangements with a faculty sponsor prior to registration for this course.

ELE E 493 MicroElectro Mechanical Systems (MEMS)

Spring. 3 credits. Prerequisite: ELE E 210 or permission of instructor.

Introductory course to MEMS: microsensors, microactuators, and microrobots. Fundamentals of MEMS including materials, microstructures, devices and simple microelectromechanical systems, scaling electronic and mechanical systems to the micrometer/nm-scale, material issues, and the integration of micromechanical structures and actuators with simple electronics. This is an interdisciplinary course drawing content from mechanics, materials, structures, electronic systems, and the disciplines of physics and chemistry.

ELE E 494 Distribution Automation and Control for Electric Power Networks

Spring. 4 credits.

Distribution automation is a system that enables an electric utility to monitor, control, and operate distribution systems in a real-time mode from remote locations. This course will cover modeling of distribution networks, three-phase unbalanced power flow analysis and short circuit calculations, state estimation, operation and control strategies, communication systems, and computer systems for distribution automations.

ELE E 495–499 Special Topics in Electrical Engineering

1–4 credits.

Seminar, reading course, or other special arrangement agreed on by the students and faculty members concerned.

ELE E 515–516 Applied Signal Processing Systems Design

515, fall; 516, spring. Variable credits.

Project-level design of systems in the area of signal processing and general instrumentation, including digital signal processing hardware, audio, speech, and analog interfacing. Students pursue individual projects and coordinate ideas and resources with other students with related interest.

ELE E 521 Theory of Linear Systems

Fall. 4 credits. Prerequisite: ELE E 302 or permission of instructor. Recommended: a good background in linear algebra and linear differential equations.

State-space and multi-input-multi-output linear systems in discrete and continuous time. The state transition matrix, the matrix exponential, and the Cayley-Hamilton theorem. Controllability, observability, stability, realization theory. At the level of *Linear Systems*, by T. Kailath.

ELE E 522 Nonlinear Systems: Analysis, Stability, Control, and Applications

Spring. 4 credits. Prerequisites: ELE E 521 or a solid background in linear algebra and real analysis strongly recommended but not required.

A fairly rigorous introduction to nonlinear systems, including nonlinear differential equations, flows, phase-plane analysis, fundamentals of Lyapunov theory, LaSalle's Theorem, regions of attraction, slowly varying systems, advanced stability theory, Lyapunov redesign, applied nonlinear control, describing functions, averaging and singular perturbations; bifurcation analysis and control and application to physical systems.

ELE E 525 Adaptive Filtering in Communication Systems

Fall. 4 credits. Prerequisite: ELE E 468.

Fundamentals of an adaptive filter theory intended for digital communication systems applications. Traditional problem, e.g., channel equalization for intersymbol interference removal, is used to motivate adaptive filter design and to raise issues of current interest. Assignments will consist of reports on adoptive digital filter and simulated evaluation.

ELE E 526 Advanced Signal Processing
Fall. 4 credits. Prerequisites: ELE E 425.
Sampling and signal reconstruction. Approximation theory. Linear inversion theory. Exponential signal modeling. Spectral estimation. Wavelets.

ELE E 530 Fiber and Integrated Optics
Spring. 4 credits with lab. Prerequisite: ELE E 303 or equivalent.
Physical principles of optical waveguides, optical sources and detectors, noise, modulators, and sensing. Wave equation solutions to the mode structure in waveguides, mode coupling, dispersion and bandwidth limitations, optical sources based on semiconductors, detectors and noise, modulation techniques, nonlinear effects in optical waveguides, and optical sensors.

ELE E 531 Quantum Electronics I
Fall. 4 credits. Prerequisites: ELE E 306 and 407, or PHYS 443.
A detailed treatment of the physical principles underlying lasers, related fields, and applications. Topics include the interaction of radiation and matter, including emission, absorption, scattering, and basic spectroscopic properties of key laser media; theory of the laser, including methods of achieving population inversions, dispersive effects, and laser oscillation spectrum.

[ELE E 532 Quantum Electronics II
Spring. 4 credits. Prerequisite: ELE E 531 or permission of instructor. Not offered 1997–98.
A continuation of ELE E 531. Topics include density matrix; nonlinear optical processes; properties of nonlinear optical materials; optical parametric oscillators; spontaneous and stimulated Raman and Brillouin processes; theory of coherence; pico- and femto-second optics; ultrafast processes in semiconductors and molecules; optical properties of semiconductor-doped glasses, quantum-well structures, and superlattices.]

ELE E 533 Semiconductor Lasers
Spring. 3 credits. Prerequisites: ELE E 430, ELE E 457, or permission of instructor.
Study of principles and characteristics of semiconductor lasers. Topics cover laser dynamics, noise, quantum confined structures, single-frequency lasers, traveling-wave lasers, surface-emitting lasers, reliability, and emerging research subjects. A term project and paper will be required.

ELE E 534 Microwave Solid State Devices
Spring. 4 credits. Prerequisites: ELE E 433 and ELE E 457. May be taken for 3 credits without lab. Prerequisites: ELE E 433 and ELE E 435. 3 lectures, 1 lab.
Basic theory of operation of solid-state microwave and millimeter wave devices: field effect transistor (FET), high electron mobility transistor (HEMT), Schottky, IMPATT, Gunn, PIN, and tunnel devices. Emphasis on how to integrate these devices into practical circuits. Oscillators, amplifiers, and mixers will be fabricated and measured in the laboratory.

ELE E 535 Semiconductor Physics
Fall. 4 credits. Prerequisites: ELE E 457 and 407, or permission of instructor.
Physics of materials and structures useful in semiconductor electronic and photonic devices, including crystal structure, energy bands, effective mass, phonons, classical low-field transport, high-field and ballistic charge carrier transport, electron scattering by phonons, optical absorption, reflection, optical emissions, deep levels as charge carrier traps, surface and interface effects. On the level of *Compound Semiconductor Device Physics* by S. Tiwari.

ELE E 536 VLSI Technology
Spring. 4 credits. 3 credits without laboratory with permission of instructor. Prerequisites: ELE E 453 or ELE E 457 or ELE E 439 or equivalent or permission of instructor.
Microfabrication for silicon very large scale integrated circuits (VLSI), microelectromechanics (MEMS), compound semiconductors (CS), and optoelectronics. Lithography, diffusion, ion implantation, thin film deposition, and etching. Process integration for CMOS, BiCMOS and ECL VLSI, MEMS, CS LSI, and optoelectronics. Hands-on MOS/MFMS fabrication, characterization, and simulation laboratory.

ELE E 537 Computer System Packaging
Spring. 4 credits. 3 credits without project with permission of instructor. Prerequisites: ENGRD 231, ELE E 232 and (ELE E 453 or ELE E 457 or ELE E 439); or permission of instructor.
Physical integration of circuits, packages, boards, and full electronic systems. Computer (portable, desktop, cabinet levels) and telecommunication (cellular telephone, base station, switch levels) system applications. Packaging architecture; electrical, optical signal distribution; power distribution; signal integrity; power, thermal management, mixed signals, manufacturing, measurements, and simulation. Case studies. Lectures include industry experts.

ELE E 539 Practicum in VLSI Design
Fall and spring (year-long course). 2 credits each semester. Prerequisites: ELE E 475 or consent of instructor. Corequisite: ELE E 439.
A year-long implementation project related to ELE E 439. Students will design a chip and have it fabricated in the fall semester and test it for functionality and performance in the spring semester. Students are required to take the course both fall and spring.

ELE E 541 Advanced Computer Architectures
Fall. 3 credits. Prerequisite: ELE E 308 (or COM S 280 and 314). May not be offered 1997–98.
Design and evaluation of processor architectures are examined in the light of actual implementations. Topics include parallel and pipelined architectures, interleaved memories, cache and virtual memories, I/0 processors, vector and array processors, protection mechanisms, and RISC architectures.

[ELE E 542 Parallel Processing
Spring. 3 credits. Prerequisite: ELE E 541. Not offered 1997–98.
Parallel computer systems that are designed to provide a high computation rate for large specific problems are studied. Topics include computer architecture, interconnection networks, performance characterization, basic algorithms, and parallel programming techniques. Recent multicomputers and massively parallel processors are also discussed.]

ELE E 546 Broad Band Information Networks
Spring. 3 credits. Prerequisite: ELE E 445 or consent of the instructor. 3 lecs.
Evolution of network architectures for integrated voice, data, and video services; advances in switching with an emphasis on asynchronous transfer mode (ATM); performance modeling; traffic and network management.

[ELE E 547 Computer Vision
Fall. 4 credits. Prerequisites: ELE E 308 (or COM S 280 and 314) or consent of instructor. Not offered 1997–98.
Computer acquisition and analysis of image data with emphasis on techniques for robot vision. This course will concentrate on descriptions of objects at three levels of abstraction: segmented images (images organized into subimages that are likely to correspond to interesting objects), geometric structures (quantitative models of image and world structures), and relational structures (complex symbolic descriptions of images and world structures). The programming of several computer-vision algorithms will be required.]

ELE E 548 Digital Image Processing
Spring. 3 credits. Prerequisites: ELE E 411, ELE E 425, familiarity with linear algebra.
Introduction to image processing through seven major topics: perception, statistical modeling, transforms, enhancement, analysis, compression, and restoration. Special attention is allocated to compression. Equal emphasis will be placed on gaining a mathematical and an intuitive understanding of algorithms through actual image manipulation and viewing.

ELE E 549 Visual Motion Seminar
Spring. 1 credit.
This seminar will provide an overview of motion as used in both coding and analysis of digital video, through examination of motion estimation and motion segmentation techniques. Topics include an introduction to digital video, techniques for computing motion, both block-based and pixel-based motion estimation, MPEG motion coding, Hausdorff-based motion estimation, motion-based tracking, and various techniques for motion segmentation. An emphasis will be placed on recent research results.

ELE E 554 Advanced VLSI Circuit Design
Spring. 4 credits. Prerequisite: ELE E 453 or equivalent.
Integration of building blocks on chip. Overview of recent innovations in VLSI circuits. Feedback circuits. Operational amplifiers. Switched-capacitor circuits. Digital-to-analog and analog-to-digital converters. Dynamic and static memories. Programmable logic and gate arrays. Systems on chips (microprocessors, wafer-scale integration).

[ELE E 555 Advanced Power Systems Analysis I
Fall. 3 credits. Prerequisites: ELE E 451, ELE E 471. A course in numerical methods would be helpful. The course is designed for first-year graduate students. Not offered 1997–98.
Topics include electromagnetic transients, synchronous machine modeling, synchronous machine control models, single-machine dynamic models, multimachine dynamic models, multimachine simulation using a differential-algebraic model, small-signal analysis of power systems, direct methods for stability analysis including potential energy boundary surface methods, regions of

attraction, exit point method and voltage stability using energy functions.]

ELE E 556 Advanced Power Systems Analysis II
Spring. 3 credits. Prerequisite: ELE E 451.
Advanced topics in electric power system analysis. These include advanced control and analysis methods for dynamic contingencies such as voltage collapse and loss of synchronism, simulation methods for large-scale nonlinear analysis; methods for system protection with emphasis on digital relaying.

ELE E 558 Compound Semiconductor Electronics
Spring. 4 credits with lab. Prerequisites: ELE E 457 or equivalent.
Electronic properties of advanced semiconductor structures using compound semiconductor materials and heterojunctions. Fundamentals of carrier transport and scattering. Properties of direct bandgap semiconductors and quantum wells. Advanced semiconductor devices including metal-semiconductor transistors (FETs), modulation-doped FETs, and heterojunction bipolar transistors (HBTs). High-frequency operation of compound semiconductor devices. Six two-week labs, which include low-temperature carrier transport, optical absorption and emission, and electrical characterization of compound semiconductor devices.

ELE E 561 Error-Control Codes
Fall. 4 credits. Prerequisite: ELE E 301 or ELE E 521 or equivalent. A strong familiarity with linear algebra is assumed.
An introduction to the theory of algebraic error-control codes. Topics include: Hamming codes, group codes, the standard array, minimum-distance decoding, cyclic codes, and the dual of a linear block code. Hamming and Singleton bounds for error-correcting codes. The construction and decoding of Bose-(Ray) Chaudhuri-Hocquenghem (BCH) and Reed-Solomon (RS) codes. Computer methods for the study of the structure and algorithms for error-control are used.

ELE E 562 Fundamental Information Theory
Fall. 4 credits. Prerequisite: ELE E 310 or equivalent.
Fundamental results of information theory with application to storage, compression, and transmission of data. Entropy and other information measures. Block and variable-length codes. Channel capacity and rate-distortion functions. Coding theorems and converses for classical and multiterminal configurations. Gaussian sources and channels.

ELE E 563 Communication Networks
Spring. 4 credits. Prerequisite: ELE E 411 or permission of instructor.
Classical line-switched communication networks: point-process models for offered traffic; blocking and queuing analyses. Stability, throughput, and delay of distributed algorithms for packet-switched transmission of data over local-area and wide-area nets: using various protocols, TDMA. Flow control and capacity assignment algorithms for wideband circuit-switched and ATM networks.

[ELE E 564 Decision Making and Estimation
Fall. 4 credits. Prerequisite: coregistration in ELE E 411. Not offered 1997–98.
An introduction to those methods of making rational decisions and inferences and of forming estimates that are central to problems of communications, detection, pattern recognition, and statistical signal processing. Topics include Bayes, minimax, and Neyman-Pearson decision theories; Bayes and maximum likelihood point estimation; Cramer-Rao bound, efficient, and consistent estimation; spectral estimation; and robust models for signal extraction.]

ELE E 566 Wireless Networks
Spring. 4 credits. Prerequisites: ELE E 445 and ELE E 411.
An introductory course in mobile and wireless networks. The course is targeted at the graduate level, but is open to undergraduates. The course covers fundamental techniques in design and operation of first and second generation wireless networks: cellular systems, medium access techniques, control of a mobile session and a mobile call, signaling in mobile networks, mobility management techniques, common air protocols (AMPS, IS-136, IS-95, GSM), wireless data networks (CDPD, Mobitex), Internet mobility, Personal Communication Services (PCS), etc.

ELE E 567 Topics in Digital Communications
Spring. Offered as 2 or 4 credits. Prerequisites: ELE E 562.
Fundamental topics in modern digital communication. Analytical and computational tools required to understand modern data conversion, transmission, and storage systems. Possible topics include: PCM, DPCM, PAM, PSK, FSK, matched filtering, equalization, line codes, trellis codes, Viterbi decoding, applications to audio, video, and magnetic recording. Vector quantization and universal data compression including LZ, LZW, and arithmetic coding, applied to files, speech, images, and video.

ELE E 577 Artificial Neural Networks
Fall. 4 credits. Prerequisites: ELE E 310; ELE E 411 recommended.
Artificial neural networks are brainlike in being formed out of many highly interconnected nonlinear memoryless elements. Probability theory will provide our primary analytical approach to design and analysis of neural networks. The course will cover mathematical and computer-based design capabilities of feed-forward nets (multilayer perceptrons) that can serve as pattern classifiers.

ELE E 581 Introduction to Plasma Physics (also A&EP 606)
Fall. 4 credits. Prerequisites: ELE E 303 and ELE E 304 or equivalent. First-year graduate-level course; open to exceptional seniors with permission of instructor.
Plasma state; motion of charged particles in fields; drift-orbit theory; coulomb scattering, collisions; ambipolar diffusion; elementary transport theory; two-fluid and hydromagnetic equations; plasma oscillations and waves, CMA diagram; hydromagnetic stability; elementary applications to space physics, plasma technology, and controlled fusion.

ELE E 582 Basic Plasma Physics (also A&EP 607)
Spring. 4 credits. Prerequisites: ELE E 581 or A&EP 606.
Boltzmann and Vlasov Equations; dielectric tensor; waves in hot-magnetized plasma; Landau and cyclotron damping; microinstabilities; drift waves, low-frequency stability; test particles, Cerenkov emission; fluctuations; collisional effects; applications.

ELE E 583 Electrodynamics
Fall. 4 credits. Prerequisite: ELE E 301 and ELE E 304 or equivalent. 3 lecs.
Maxwell's equations, electromagnetic potentials, integral representations of the electromagnetic field, Green's functions. Special theory of relativity, Lienard-Wiechert potentials, radiation from accelerated charges, Cerenkov radiation. Electrodynamics of dispersive dielectric and magnetic media. At the level of *Classical Electrodynamics*, by Jackson.

ELE E 584 Microwave Theory
Spring. 4 credits. Prerequisites: ELE E 301 and 304 or equivalent. 3 lecs, 1 rec.
Theory of passive microwave devices. Modal analysis of inhomogeneous waveguides and cavities. Waveguide excitation, perturbation theory. Nonreciprocal waveguide devices. Scattering matrix analysis of multiport junctions, resonant cavities, directional couplers, circulators. Periodic waveguides, coupled-mode theory.

ELE E 586 Upper Atmosphere Physics II (also ASTRO 576)
Spring. 3 credits.
High-latitude ionosphere; electric fields in the polar cap and auroral zone; particle precipitation and the aurora; magnetic and ionospheric storms; plasma instabilities in the ionosphere and magnetosphere; structure and physical processes in the sun, solar corona, and solar wind; interactions between the solar wind and the earth's magnetosphere; trapping, acceleration, and drift of energetic particles in the magnetosphere.

[ELE E 587 Energy Seminar (also NS&E 545 and M&AE 545)
Fall and spring. 1 credit each semester. Students may take this seminar both fall and spring for credit. 1 lec. Not offered 1997–98.
Energy resources, their conversion to electricity or mechanical work, and the environmental consequences of the energy cycle will be discussed by faculty members from several departments in the University, and by outside experts. Examples of topics to be surveyed are energy resources, and economics, coal-based electricity generation; nuclear reactors; solar power; energy conservation by users; and air-pollution control.]

[ELE E 588 Advanced Electromagnetic Wave Propagation and Scattering
Spring. 3 credits. Prerequisite: ELE E 487 and 581 or permission of instructor. Offered alternate years. Not offered 1997–98.
WK band and full-wave solutions of the wave equations, interactions between particles and waves, scattering of radio waves from random fluctuations in refractive index, scatter propagation, incoherent scatter from the ionosphere and its use as a diagnostic tool, scattering from unstable plasma waves, pulse compression and other radar probing techniques.]

ELE E 593 Bioelectric Signal Analysis and Processing
Fall. 3 credits with lab. Prerequisites: ELE E 301, ELE E 315, and a knowledge of C programming and MATLAB. ELE E 425 helpful.
Measurement and computer-aided analysis of low-level biological signals in the presence of background noise. Electrocardiography, A/D conversion, filtering, signal conditioning, and

data compression techniques will be investigated using the human surface ECG as signal source. Pattern classification and microcontroller instrumentation design will be introduced. Final team design projects are required.

ELE E 594 Mobile Communication Systems
Spring. 4 credits. Prerequisite: ELE E 411; Corequisite: ELE E 468.
Theory and analysis of mobile communication systems, with an emphasis on understanding the unique characteristics of these systems. Topics include: cellular planning, mobile radio propagation and path loss, characterization of multipath and fading channels, modulation and equalization techniques for mobile radio systems, source coding techniques, multiple access alternatives, CDMA system design, and capacity calculations. Some lectures will be given by industry researchers.

ELE E 595–599 Graduate Topics in Electrical Engineering
1–4 credits.
Seminar, reading course, or other special arrangement agreed on by the students and faculty members concerned.

ELE E 633 Radiation Effects in Microelectronics (also NS&E 621)
For description, see NS&E 621.

ELE E 691–692 Electrical Engineering Colloquium
691, fall; 692, spring. 1 credit each term. For students enrolled in the graduate Field of Electrical Engineering.
Lectures by staff, graduate students, and visiting authorities. A weekly meeting for the presentation and discussion of important current topics in the field. Reports required.

ELE E 693–694 Master of Engineering Design
693, fall; 694, spring. 1–10 credits. For students enrolled in the M.Eng.(Electrical) degree program. Uses real engineering situations to present fundamentals of engineering design. Each professor is assigned a section number. To register, see roster for appropriate 6-digit course ID numbers.

ELE E 695–699 Graduate Topics in Electrical Engineering
1–6 credits.
Seminar, reading course, or other special arrangement agreed on by the students and faculty members concerned. See M.Eng. office for course registration procedure.

ELE E 791–792 Thesis Research
791, fall; 792, spring. 1–15 credits. For students enrolled in the master's or doctoral program.

GEOLOGICAL SCIENCES

Courses

For complete course descriptions, see the Geological Sciences listing in the College of Arts and Sciences section.

GEOL 101 Introductory Geological Sciences
Fall, spring, summer. 3 credits.

GEOL 102 Evolution of the Earth and Life (Bio G 170)
Spring, summer. 3 credits.

GEOL 104 The Sea: An Introduction to Oceanography (BIO ES 154)
Spring, summer. 3 or 4 credits (4 credits with lab section).

GEOL 105 Writing on Rocks (Freshman Seminar)
Fall. 3 credits.
See Freshman Seminar handbook for description.

GEOL 106 Vertebrate Fossil Preparation
Spring. 1 credit. Prerequisites: one introductory geology course or concurrent enrollment; class size is limited.

GEOL 107 How the Earth Works
Fall. 1 credit.

[GEOL 108 Geology and Society
Spring. 1 credit. May be taken concurrently with or after GEOL 101, 102, 104, 111, 201, or 206.]

GEOL 109 Dinosaurs
Fall. 1 credit.

GEOL 111 To Know the Earth and Build a Habitable Planet
Fall. 3 credits.

GEOL 122 Earthquake! (also ENGRI 122)
Fall. 3 credits.
For course description, see ENGRI 122.

GEOL 123–124 Science of Earth Systems Colloquium (also ABEN 120–121, SCAS 101–102 and SES 101–102)

GEOL 125 Global Environment (also ENGRI 125)
Fall. 3 credits.
For course description, see ENGRI 125.

GEOL 201 Introduction to the Physics and Chemistry of the Earth (also ENGRD 201)
Spring. 3 credits. Prerequisites: MATH 191 and PHYS 112.
For course description, see ENGRD 201.

GEOL 203 Natural Hazards and the Science of Complexity
Fall. 3 credits. 1 course in calculus.

GEOL 210 Introduction to Field Methods in Geological Sciences
Fall. 3 credits. Prerequisite: GEOL 101 or 201, or permission of instructor. Weekly field sessions. A weekend field trip.

GEOL 212 Special January Field Trip
Fall. 2 credits. Prerequisites: GEOL 101 or 201 or equivalent, and permission of instructor. Travel and subsistence expenses to be announced.

GEOL 213 Marine and Coastal Geology
Summer. 2 credits. Prerequisites: an introductory course in geology or permission of instructor.

GEOL 214 Western Adirondack Field Course
Spring. 1 credit. Prerequisite: GEOL 210 or equivalent, or permission of instructor.

Junior, Senior, and Graduate Courses

Of the following, the core courses GEOL 326, 355, 356, 375, and 388 may be taken by B.S. candidates who have successfully completed GEOL 201 or the equivalent and by B.A. candidates who have completed GEOL 101 or the equivalent, or who can demonstrate to the instructor that they have adequate preparation in mathematics, physics, chemistry, biology, or engineering.

GEOL 302 Evolution of the Earth System (also SES 332 and SCAS 302)
For course description, see the Science of Earth Systems section in "Interdisciplinary Centers, Programs, and Studies," in the front part of the catalog.

GEOL 321 Introduction to Biogeochemistry (also SES 321, NTRES 321)
Fall. 4 credits. Prerequisites: college-level chemistry, plus a course in biology and/or geology.

GEOL 326 Structural Geology
Spring. 4 credits. Prerequisite: GEOL 101 or 201, or permission of instructor.

GEOL 355 Mineralogy
Fall. 4 credits. Prerequisite: GEOL 101 or 201 and CHEM 207 or permission of instructor.

GEOL 356 Petrology and Geochemistry
Spring. 4 credits. Prerequisite: GEOL 355.

GEOL 375 Sedimentology and Stratigraphy
Fall. 4 credits. Prerequisite: GEOL 101, 102, or 201.

GEOL 388 Geophysics and Geotectonics
Spring. 4 credits. Prerequisites: MATH 192 and PHYS 208, 213, or equivalent.

GEOL 411 Satellite Remote Sensing of Glaciers, Earthquakes, and Erosion
Fall. 3 credits.

GEOL 417 Field Mapping in Argentina
Summer. 3 credits. Prerequisites: GEOL 210 and GEOL 326; Spanish desirable, but not required.

GEOL 423 Petroleum Geology
Fall. 3 credits. Recommended: GEOL 326. Offered alternate years.

GEOL 434 Reflection Seismology
Spring. 4 credits. Prerequisites: MATH 192 and PHYS 208, 213, or equivalent.

GEOL 437 Geophysical Field Methods
Fall. 3 credits. Prerequisites: PHYS 213 and MATH 192 or equivalents, or permission of instructor.

GEOL 445 Geohydrology (also ABEN 471 and CEE 431)
Fall. 3 credits. Prerequisites: MATH 294 and ENGRD 202.
For description, see CEE 431.

GEOL 452 X-ray Diffraction Techniques
Spring. 3 credits. Prerequisite: GEOL 355 or permission of instructor. Offered alternate years.

[GEOL 453 Advanced Petrology
Fall. 3 credits. Prerequisite: GEOL 356. Offered alternate years. Not offered 1997–98.]

[GEOL 454 Advanced Mineralogy
Spring. 3 credits. Prerequisite: GEOL 355 or permission of instructor. Offered alternate years. Not offered 1997–98.]

GEOL 455 Geochemistry
Fall. 4 credits. Prerequisites: CHEM 207 and MATH 102, or equivalent. Recommended: GEOL 356. Offered alternate years.

[GEOL 458 Volcanology
Spring. 3 credits. Corequisite: GEOL 356 or equivalent. Offered alternate years. Not offered 1997–98.]

GEOL 475 Special Topics in Oceanography
Spring, summer. 2–5 var. credits. Prerequisites: GEOL 104 or BIO ES 154 and permission of instructor.

[GEOL 476 Sedimentary Basins: Tectonics and Mechanics
Spring. 3 credits. Prerequisite: GEOL 375 or permission of instructor. Offered alternate years. Not offered 1997–98.]

[GEOL 478 Advanced Stratigraphy
Spring. 3 credits. Prerequisite: GEOL 375 or permission of instructor. Offered alternate years. Not offered 1997–98.]

GEOL 479 Paleobiology (also BIO ES 479)
Fall. 3 credits. Prerequisites: one year of introductory biology for majors and either BIO ES 274, 373, GEOL 375, or permission of instructor. Offered alternate years.

GEOL 481 Senior Survey of Earth Systems
Fall. 3 credits. Limited to seniors majoring in geological sciences.

GEOL 491–492 Undergraduate Research
Fall, spring. 1 or 2 credits variable.

GEOL 500 Design Project in Geohydrology
Fall, spring. 3–12 credits. An alternative to an industrial project for M.Eng. students choosing the geohydrology option. May continue over two or more semesters.

GEOL 502 Case Histories in Groundwater Analysis
Spring. 4 credits.

[GEOL 622 Advanced Structural Geology I
Spring. 3 credits. Prerequisites: GEOL 326 and permission of instructor. Offered alternate years. Not offered 1997–98.]

[GEOL 624 Advanced Structural Geology II
Spring. 3 credits. Prerequisites: GEOL 326 and permission of instructor. Offered alternate years. Not offered 1997–98.]

GEOL 628 Geology of Orogenic Belts
Spring. 3 credits. Prerequisite: permission of instructor.

[GEOL 634 Advanced Geophysics I: Fractals and Chaos in Geology and Geophysics
Spring. 3 credits. Prerequisite: GEOL 388 or permission of instructor. Offered alternate years. Not offered 1997–98.]

[GEOL 636 Advanced Geophysics II: Quantitative Geodynamics
Spring. 3 credits. Prerequisite: GEOL 388 or permission of instructor. Offered alternate years. Not offered 1997–98.]

GEOL 651 Analysis of Biogeochemical Systems
Spring. 3 credits. Prerequisite: MATH 293 or permission of instructor. Offered alternate years.

GEOL 656 Isotope Geochemistry
Spring. 3 credits. Open to undergraduates. Prerequisites: GEOL 455 or permission of instructor. Offered alternate years.

GEOL 681 Geotectonics
Fall. 3 credits. Prerequisites: permission of instructor.

GEOL 695 Computer Methods in Geological Sciences
Fall, spring. 3 credits.

GEOL 700–799 Seminars and Special Work
Fall, spring. 1–3 credits. Prerequisite: permission of instructor.
Advanced work on original investigations in geological sciences. Topics change from term to term. Contact appropriate professor for more information.

[GEOL 722 Advanced Topics in Structural Geology
Not offered 1997–98.]

GEOL 731 Plate Tectonics and Geology

GEOL 733 Fractals and Chaos—Independent Studies

GEOL 751 Petrology and Geochemistry

GEOL 753 Advanced Topics in Mineral Physics

GEOL 755 Advanced Topics in Petrology and Tectonics

GEOL 757 Current Research in Petrology

GEOL 762 Advanced Topics in Petroleum Exploration
Fall.

[GEOL 771 Advanced Topics in Sedimentology and Stratigraphy
Not offered 1997–98.]

GEOL 773 Paleobiology

GEOL 775 Advanced Topics in Oceanography
Spring.

GEOL 780 Earthquake Record Reading
Fall.

GEOL 781 Geophysics, Exploration Seismology

GEOL 783 Advanced Topics in Geophysics

GEOL 789 Lithospheric Seismology (COCORP Seminar)

GEOL 793 Andes-Himalaya Seminar

GEOL 795 Low-Temperature Geochemistry

GEOL 796 Geochemistry of the Solid Earth

GEOL 797 Fluid-Rock Interactions

GEOL 799 Soil, Water, and Geology Seminar

MATERIALS SCIENCE AND ENGINEERING

Undergraduate Courses

MS&E 111 Materials by Design (also ENGRI 111)
Fall. 3 credits. E. P. Giannelis.
For description, see ENGRI 111.

MS&E 118 Design Integration: A Portable CD Player (also ENGRI 118)
Spring. 3 credits. W. Sachse.
For description, see ENGRI 118.

MS&E 124 Designing Materials for the Computer
Spring. 3 credits. 3 lectures. C. K. Ober.
For description, see ENGRI 124.

MS&E 222 Materials Chemistry
Spring. 3 credits. E. P. Giannelis.
This course is designed to show how materials chemistry has enabled modern technology. Topics will include conducting polymers, organic LEDs, self-assembling materials, contact lithography, nanophase and nanocrystalline materials, catalysis, smart gels, dendrimers, buckytubes, aerogels, chemistry of surfaces, molecular magnets, bioinspired materials, light harvesting polymers, inorganic polymers.

MS&E 261 Introduction to Mechanical Properties of Materials (also ENGRD 261)
Fall. 3 credits. S. L. Sass.
For description, see ENGRD 261.

MS&E 265 Biological Materials and Their Synthetic Replacements
Fall. 3 credits. D. T. Grubb.
From contact lenses and false teeth to arterial implants and hip joints, a tremendous range of synthetic materials are used in contact with the body to replace or supplement natural biological materials. The course will consider a number of biological systems and describe the properties and structure of the natural materials. Requirements for candidate replacement materials will be discussed, with historical and current solutions. These involve material properties such as strength and corrosion resistance as well as toxicity and bio-compatibility. Design constraints, including methods of production, economics, regulatory approval, and legal liabilities, will also be considered.

[MS&E 277 The Substance of Civilization—Materials through the Ages
Spring. 3 credits. 2 lecs, 1 lab. Not offered 1997–98. S. L. Sass.
Materials have enabled revolutionary advances in how we live, work, fight, travel, and play; hence the naming of eras after them—Stone, Bronze, and Iron Ages. This course explores the role of materials in the development of the modern Western industrial civilization by putting technology into a historical context and examining the advances made possible by innovations with materials, starting with the Stone Age. Interconnections between critical developments are identified and explored—for example, the relationship between materials, agriculture, and written languages in the fourth millennium B.C., and between the Exodus of the Hebrews, the general tumult in the Eastern Mediterranean, and the onset of the Iron Age, at the end of the second

millennium B.C. Early technologies will be illustrated with beautiful works of art. Lectures, demonstrations, and hands-on laboratory experiments, will elucidate the origin of the unique properties of materials such as polymers, ceramics, metals and glass. This course is designed to fulfill the science requirement in the College of Arts and Sciences.]

MS&E 285 Art, Archaeology, and Analysis (also ARKEO 285, ART 372, ENGRI 185 and NS&E 285 and PHYS 200)
Spring. 3 credits.
For description, see ENGRI 185.

MS&E 331/531 Structure of Materials
Fall. 4 credits. D. T. Grubb.
Bonding in materials, crystal structures and symmetry, defects. Crystal planes and directions, stereographic projections, texture. Techniques for structural analysis: Direct and diffraction methods. X-ray and electron diffraction, optical and electron microscopy. Experimental systems for structural characterization of materials.

MS&E 332/532 Electrical and Magnetic Properties of Materials
Spring. 3 credits. Prerequisite: MS&E 331 or permission of instructor. Y. Suzuki.
Introduction to electronic band structure of crystals. Electrical and magnetic properties of metals and semiconductors. Electron transport. Design of semiconductor properties by doping. Carrier statistics. Properties of junctions in semiconductor devices. Principles and design of ferromagnetic materials for transformers, permanent magnets, and magnetic memory devices. Ionic conductivity. Fundamentals of superconducting materials for high-field magnets and Josephson junctions. Introduction to dielectric and optical properties.

MS&E 333 Research Involvement I
Fall. 3 credits. Prerequisite: approval of course coordinator. Staff.
Supervised independent research project in association with faculty member and faculty research group of the department. Students design experiments, set up the necessary equipment, and evaluate the results. Creativity and synthesis are emphasized.

MS&E 334 Research Involvement II
Spring. 3 credits. Prerequisite: approval of department. Staff.
See MS&E 333 for description. May be a continuation of MS&E 333 or a one-term affiliation with a research group.

MS&E 335/535 Thermodynamics of Condensed Systems
Fall. 4 credits. Prerequisites: MATH 293 and 294. M. O. Thompson.
The three laws of thermodynamics are introduced as a basis for understanding phase equilibria, heterogeneous reactions, solutions, electrochemical processes, surfaces, and defects. Statistical mechanics is introduced and applied to the calculation of entropy and specific heat of ideal gases and solids. Examples of design and control of processes.

MS&E 336/536 Kinetics, Diffusion, and Phase Transformations
Spring. 3 credits. Prerequisite: MS&E 335 or permission of instructor. R. Dieckmann.
Introduction to electrochemistry, atomic motion, and diffusion. Applications and design involving nucleation and growth of new phases in vapors, liquids, and solids; solidification, crystal growth, corrosion, recrystallization, gas-metal reactions, and thermomechanical processing to produce desired microstructures and properties. One-third of course involves examples of design and control of processes.

MS&E 345 Mechanical Properties and Processing of Engineering Materials (also M&AE 212)
Spring. 3 credits. Prerequisite: ENGRD 202. N. Zabaras.
For description, see M&AE 212.

[MS&E 414/514 Chemical Processing of Ceramics
Spring. 3 credits. Not offered 1997–98. E. P. Giannelis.
Design and characterization of materials at the molecular level. Synthesis, drying, and sintering of ceramics, glasses, and composites. Sol-gel, hydrothermal, chemical-vapor deposition, and pyrolysis techniques. Surface chemistry of oxides. Analytical techniques include chromatography, mass spectrometry, infrared, uv-visible and nuclear-magnetic resonance spectroscopy. Design, synthesis, and chemical properties of inorganic/organometallic precursors. Ceramic thin films, fibers whiskers, and membranes.]

MS&E 435 Senior Thesis I & II
Fall and spring. 2-semester course. 8 credits. Staff.
Open to advanced undergraduates in lieu of the senior materials laboratory. Proposals for thesis topics should be approved by the supervising faculty member prior to beginning the senior year. Approved thesis topics will normally involve original experimental research in direct collaboration with an ongoing research program. Periodic oral and written presentations and a final written thesis are required. This course is required for graduation with honors.

MS&E 441/541 Microprocessing of Materials
Fall. 3 credits. J. Nucci.
Materials and processing steps involved in the production of integrated circuits and other micro-devices. Science, engineering, and design of processes to produce a specific device, such as a DRAM or CMOS inverter (not detailed electrical-circuit analysis of these devices or system design). Emphasis is on silicon, with extensions to gallium arsenide. All fabrication steps are considered, from single crystal growth and wafer production, to characterization, testing and yield calculations. Major topics are thermal oxidation of silicon, chemical vapor deposition of thin films, diffusion, ion implantation, resists and the principles of lithography using UV, electrons and X-rays, and wet/dry etching.

MS&E 442/542 Macroprocessing
Spring. 3 credits.
Deformation and macro-processing of materials; sheet metals forming, superplastic forming, casting, single crystal growth, powder sintering metal/ceramic joining, surface treatments. Course based on case studies demonstrating various macro-processing techniques. Course includes comprehensive experimental project involving design, measurement, and analysis of superplastic forming process starting from basic mechanisms. Results compared with the predictions of numerical analysis.

MS&E 443–444 Senior Materials Laboratory
443, fall; 444, spring. 3 credits each term. D. T. Grubb.
Practical laboratory covering the analysis and characterization of materials and processing. Emphasis on design of experiments for evaluation of materials' properties and performance as related to processing history and microstructure. Projects available in areas such as plasticity, mechanical and chemical processing, phase transformations, electrical properties, magnetic properties, and electron microscopy.

MS&E 445 Mechanical Properties of Materials
Fall. 3 credits. Prerequisites: MS&E 331 and 336, or permission of instructor. A. L. Ruoff.
Stress, strain, and the basics of concepts in deformation and fracture for metals, polymers, and ceramics. Analysis of important mechanical properties such as plastic flow, creep, fatigue, fracture toughness, and rupture. Application of these principles to the design of improved materials and engineering structures.

MS&E 447/448 Materials Design Concepts I & II
447, fall; 448, spring. 2 credits each term. C. K. Ober, Y. Suzuki.
Defines design in the field of materials science using Dieter's *Engineering Design,* Ashby's *Materials Selection in Engineering Design,* and other sources. Innovation, patent searching, and ASTMS standards. Speakers from industry and other institutions lecture on case studies of design problems. Students give short oral and written presentations. Proposal for design-study project in the fall semester. Completion of extensive design-study project in the spring semester. Study includes prior art literature, materials selection, and some modeling, as well as discussion of broader economic, regulatory, environmental, and liability concerns that may arise.

MS&E 449 Introduction to Ceramics
Fall. 3 credits. Prerequisite: MS&E 331 or permission of instructor. R. Dieckmann.
Ceramic processes and products, crystal structures, structure of glasses, point defects (point-defect chemistry and relation to nonstoichiometry), line defects, grain boundaries, diffusion in ionic materials (emphasis on the relationships between diffusion and point-defect structure), phase diagrams, phase transformations, kinetics of solid-state reactions (reactions with and between solids: heterogeneous reactions, reactions between different solids, point-defect relaxation, internal reactions), grain growth and sintering. Physico-chemical aspects are emphasized.

MS&E 452 Properties of Solid Polymers
Fall. 3 credits. Prerequisite: ENGR 261. Corequisite: MS&E 335/535 or permission of instructor. C. K. Ober.
Synthetic and natural polymers for engineering applications. Production and characterization of long-chain molecules. Gelation and networks, rubber elasticity, elastomers and thermosetting resins. Amorphous and crystalline thermoplastics and their structure. Time- and temperature-dependent elastic properties of polymers. Molecular-weight measurement. Design of high-impact-strength polymers.

MS&E 454 Processing of Glass, Ceramic, and Glass-Ceramic Materials
Spring. 3 credits. Offered alternate years. Recommended prerequisite: MS&E 449. R. Dieckmann.
Conventional and unconventional techniques for processing glass, glass-ceramic, and ceramic materials. Case studies illustrate the design, engineering, and scientific aspects of such processes. Vapor processes for high-purity optical fibers, hot-processing of ceramic turbine blades, photosensitive materials, and powder processing and sintering of ceramics will be discussed. This course is team taught with scientists from the research and development laboratory of Corning Glass Works.

MS&E 455 Introduction to Composite Materials (also M&AE 455 and T&AM 455)
Spring. 4 credits.
For description, see T&AM 455.

MS&E 459 Physics of Modern Materials Analysis
Spring. 3 credits. M. O. Thompson.
The interaction of ions, electrons, and photons with solids, and the characteristics of the emergent radiation in relation to the structure and composition of materials. Aspects of atomic physics that are relevant to understanding techniques of modern materials analysis. Principles of analysis techniques such as Auger electron spectroscopy, ion scattering, and secondary ion-mass spectroscopy. Design of experiments for near-surface analysis.

MS&E 463 Principles of Electronic Packaging
Spring. 3 credits. C. Y. Li.
Design, materials, and manufacturing needs for packaging technology, from chip to board. Principles involved in key areas of materials science, and other engineering disciplines. Packaging materials to be discussed include metals, ceramics, and polymers.

[MS&E 482 Plasma Processing of Electronic Materials (also ELE E 482)
Not offered 1997–98.
For description, see ELE E 482.]

MS&E 489 Undergraduate Teaching Involvement
Fall and spring. Variable credit. MS&E faculty.
This course will give credit to students who help in the laboratory portions of ENGRI 111 or 124, ENGRD 261 or MS&E 277. The number of credits earned will be determined by the teaching load and will typically be 1 to 3 credits.

MS&E 490 Independent Study
Fall and spring. Variable credit. Individual faculty.
This course is meant for students who are not yet seniors and who have already taken MS&E 333 and MS&E 334, Research Involvement, and who want to do an intense research project.

MS&E 495 Introduction to Group Theory with Applications
Fall. 2 credits. Homework only. S-U only. R. L. Liboff.
Definitions and simple properties. Symmetry operations, point groups and group multiplication tables. Sub-groups and classes. Matrix representations of groups. Irreducible representations. Basis functions. Character tables. The great orthogonality theorem. Crystallographic space groups. Ligand field theory. Permutation group, Cayley's theorem, and Young diagrams. O(3) and SU(2) groups. Tensor representations and the Wigner-Eckart theorem. Application to degeneracy, selection rules, and band structure.

At the level of: B. S. Wherrett, *Group Theory for Atoms, Molecules and Solids* (Prentice Hall, 1986); F. A. Cotton, *Chemical Applications of Group Theory*, 3rd ed. (Wiley-Interscience, 1990).

[MS&E 501 Introduction to Electron Microscopy
Fall. 1 credit. Offered alternate years. Not offered 1997–98. S. L. Sass.
This course is for undergraduates and graduate students who are interested in getting a basic foundation in transmission electron microscopy and electron diffraction techniques. This course will be particularly important for students who are planning to use the electron microscope for their undergraduate or graduate research projects. Included will be electron optics, kinematical theory of diffraction, image contrast from crystal defects, high resolution lattice imaging, and the interpretation of electron diffraction patterns. Both theoretical and practical aspects of electron microscopy are discussed.]

Graduate-Level Professional Courses

[MS&E 516 Thin-Film Materials Science
Fall. 3 credits. Offered alternate years. Not offered 1997–98. Staff.
This course is a fundamental approach to thin-film science that will cover deposition of films, growth of epitaxial layers, formation of multilayered structures such as superlattices and quantum wells, and interdiffusion and reaction in thin films. The course will begin with the structure and thermodynamics of surfaces and ultrathin films. The conditions for epitaxial growth, such as used in semiconductor heterostructures, will be contrasted with those for amorphous or polycrystalline films. The role of thermal processing for reactive thin films involving the formation of surface oxides, metallic silicides, and aluminides will be presented.]

[MS&E 518 Introduction to Electron Microscopy
Fall. 3 credits. Prerequisite: MS&E 331 or permission of instructor. Offered alternate years. Not offered 1997–98. Staff.
Basic optics and operation of scanning and transmission electron microscopes. Image formation, modes of contrast, and resolution in SEM and TEM. Electron diffraction. Images of perfect crystal and defects in two-beam diffraction contrast. Analytical microscopy; comparison of energy dispersive spectroscopy, wavelength dispersive spectroscopy and electron energy laser spectroscopy. Overview of specimen preparation and in-situ microscopy.]

[MS&E 520 Practical Electron Microscopy
Fall. 3 credits. Corequisite: MS&E 518. Limited to 12 students. A fee will be charged for instrument usage. Offered alternate years. Not offered 1997–98. Staff.
Students will be instructed in the proper use of a scanning and a transmission electron microscope. All stages from initial alignment of the instrument to presentation of the results will be covered. Three or four projects will be completed, including obtaining atomic lattice fringe images and X-ray microanalysis.]

MS&E 553–554 Special Project
553, fall; 554, spring. 6 credits each term.
Master of Engineering research project.

Graduate Core Courses

MS&E 601 Thermodynamics of Materials
Fall. 3 credits. Prerequisite: previous course in thermodynamics at level of MS&E 335. Staff.
Basic statistical thermodynamics. Partition functions and thermodynamic state functions. Distributions. Laws of thermodynamics. Free-energy functions and conditions of equilibrium. Chemical reactions. Statistics of electrons in crystals. Heat capacity. Heterogeneous systems and phase transitions. Lattice models of 1–, 2–, 3–dimensional interacting systems. Statistical thermodynamics of alloys. Free-energy and phase diagrams. Order-disorder phenomena. Point defects in crystals. Statistical thermodynamics of interfaces.

MS&E 602 Elasticity, Plastic Flow, and Fractures
Fall. 3 credits. Staff.
Micromechanical modeling of mechanical behavior. A materials-science approach to modeling combines concepts from continuum mechanics, thermodynamics, kinetics and atomic structure. Topics include: elastic properties of crystals, deformation mechanisms from ambient temperature to very high temperatures over a wide range of strain rates, fracture in brittle materials, fracture in ductile materials, fracture at elevated temperatures, crack tip phenomena, and composite materials.

MS&E 603 Analytical Techniques for Materials Science
Spring. 4 credits. Lab. M. O. Thompson.
Survey of atomic and structural analysis techniques as applied to surface and bulk materials. Physical processes involved in the interaction of ions, electrons, and photons with solids; characteristics of the emergent radiation in relation to the structure and composition. Techniques covered include Auger electron spectroscopy, ion scattering, nuclear activation, secondary ion mass spectroscopy, UV and X-ray photoelectron spectroscopies, X-ray diffraction and related techniques, etc. Selection and design of experiments for near-surface analysis.

MS&E 604 Diffusion and Phase Transformation: Kinetics in Condensed Matter
Spring. 3 credits. Staff.
Phenomenology and microscopic aspects of diffusion in fluids, both simple and polymeric, and in solids, metallic and ionic. Phase stability and transformation; nucleation and growth, spinodal decomposition and displacive transformations. Phase coarsening processes, recrystallization and grain growth. Diffusion-controlled growth, interfacial reactions, moving-boundary problems. Grain-boundary migration controlled kinetics. At the level of *Diffusion in the Condensed State*, by Kirkaldy and Young.

MS&E 605 Structure and Chemistry of Condensed Matter
Spring. 3 credits. J. M. Blakely.
This course focuses on the link between the local chemistry of the elements comprising a solid, the structure of the solid, and the bonding in the solid. Elementary aspects of group theory and representation theory. Hybridization and molecular orbital approaches to bonding extended to the solid state. Band structures and densities of states of simple crystals. Crystal structures. Structure of and bonding in surfaces, amorphous materials, glasses, and liquids. At the level of *Introduction to Group Theory with Applications*, by Burns; and *Solids and Surfaces: A Chemist's View of Bonding in Extended Structures*, by Hoffmann.

MS&E 655 Composite Materials (also M&AE 655 and T&AM 655)
Spring. 4 credits.
For description, see T&AM 655.

Related Course in Another Department
Introductory Solid-State Physics (Physics 454).

Further Graduate Courses

MS&E 610 Principles of Diffraction (also A&EP 711)
Spring. 4 credits. Offered alternate years. B. Batterman.
For description, see A&EP 711.

[MS&E 611 Modern Polymer Physics
Spring. 3 credits. Prerequisites: MS&E 452, CHEME 711, or equivalent. Offered alternate years. Not offered 1997–98.
Modern engineering plastics and polymeric matrices for fiber-reinforced composite materials often demand more detailed knowledge of polymer structure and properties in the melt or solid state than is afforded by beginning courses that emphasize polymer solutions. This course is a fundamental approach to the structure and physical properties of polymers, copolymers, and polymer mixtures, including thermodynamics, phase equilibria, diffusion, kinetics of phase separation, surfaces, and interfaces. At the level of *Scaling Concepts in Polymer Physics* by de Gennes.]

[MS&E 612 Solid-State Reactions
Fall. 3 credits. Offered alternate year. R. Dieckmann. Not offered 1997–98. Next offered 1998–99.
Point defects (thermal disorder, component-activity-dependent disorder, influence of dopants, different kinds of associates, Coulomb interaction between point defects), dislocations, grain boundaries transport in solids (definition and different types of diffusion coefficients, reference frames, mechanisms of electrical conduction, elementary diffusion mechanisms, atomic theory of transport, correlation effects, phenomenological theory of transport including some aspects of thermodynamics of irreversible processes, Fick's laws), point-defect relaxation (migration controlled, phase-boundary-reaction controlled), interdiffusion, solid-state reactions involving compound formation (oxidation of metals, reactions between solids), demixing of materials in potential gradients, selected solid-state processes (internal reactions, etc.).]

MS&E 614 Transmission Electron Microscopy
Spring. 3 credits. Prerequisite: MS&E 331 or equivalent level of knowledge of crystallography and diffraction. S. L. Sass.
This course covers the theory and practice of obtaining and interpreting TEM data from crystalline materials. Topics include specimen preparation, adjustment and calibration of the TEM, and image formation. Special emphasis is placed on electron diffraction (formation and analysis of spot patterns, Kikuchi patterns and convergent beam patterns), and obtaining useful images of crystal defects. Practical requirements for high-resolution imaging of crystal lattices and interfaces are also covered. Associated theoretical topics include kinematical and dynamical diffraction theories, including Bloch waves and anomalous absorption, the contrast transfer function theory of phase contrast, and image modeling and image analysis for quantitative interpretation of data. Current texts are Loretto *Electron Beam Analysis of Materials*, 2nd ed., and Riemer *Transmission Electron Microscopy, Physics of Image Formation.*

[MS&E 617 Solid State Electrochemistry
Fall. 3 credits. Prerequisite: MS&E 612 or permission of instructor. Offered alternate years. Not offered 1997–98; next offered 1999–2000. R. Dieckmann.
Disorder in solids; thermodynamic quantities or quasi-free electrons and electron defects in semiconductors; mobility, diffusion and partial conductivity of ions and electrons; solid ionic conductors, solid electrolytes and solid solution electrodes; galvanic cells with solid electrolytes for thermodynamic investigations; technical applications of solid electrolytes. At the level of *Electrochemistry of Solids* by H. Rickert.]

[MS&E 619 Superhard Materials
Fall. 3 credits. Prerequisite: permission of instructor. Not offered 1997–98. A. L. Ruoff.
The superhard materials include diamond, cubic boron nitride (possibly the new C_4N_3) and borderline, B_4C. The origin of their extreme hardness is examined. The thermodynamics of their stability and the kinetics of their crystal growth will be described. Commercial methods of synthesis of large crystals, powders, thin films and polycrystalline aggregates (by sintering at pressure) will be examined. Their chemical, optical and mechanical properties will be studied. Moreover, there is substantial potential for radiation-hard semi-conducting devices and the status of this area will be covered. At the level of Field, *The Properties of Natural and Synthetic Diamonds*, plus recent papers.]

[MS&E 524/624 Synthesis of Polymeric Materials
Spring. 3 credits. Alternate years. Prerequisite: MS&E 452 or permission of instructor. Not offered 1997–98. C. K. Ober.
Preparation of synthetic polymers by step- and chain-growth polymerization: condensation; free radical, anionic, and cationic mechanisms; ring opening and coordination routes. Statistical and kinetic aspects of homopolymer and copolymer formation. Stereochemistry of polymers and spectroscopic methods for polymer analysis. Molecular aspects of polymer design for properties such as conductivity, elasticity, thermal stability, and engineering properties. Special topics will include liquid crystalline polymers, photoresists, and supermolecular chemistry. At the level of *Principles of Polymerization*, by Odian.]

MS&E 626 Advanced Inorganic Chemistry III: Solid-State Chemistry (also CHEM 607)
Spring. 4 credits. Prerequisite: CHEM 605 or permission of instructor. F. DiSalvo.
The third of a three-term sequence. Interdisciplinary approach to solids. Topics include solid-state structure and x-ray diffraction, synthesis methods, defects in solids, phase diagrams, electronic structure, and chemical and physical properties of solids. Text: *Solid State Chemistry and Its Applications*, by West. Readings from inorganic chemistry and solid-state physics texts.

MS&E 671 Synthetic Polymer Chemistry (also CHEME 675 and CHEM 671)
Spring. 4 credits. Chemistry faculty.
For description, see CHEM 671.

Specialty Courses

MS&E 526 Introduction to Photonic Materials and Devices
Spring. 1 credit. M. Gupta.
Introduces students to important subject material of great practical importance: (1) Optical thin film materials and designs (optical dielectric coatings, thickness measurements, design of high reflectance and antireflectance coatings and practical examples, etc.), (2) Compound semiconductor materials and devices (GaAs, GaN and ZnSe light emitting and detecting materials and design of LED, lasers and detectors), (3) Ferroelectric materials and devices (electro-optic, piezoelectric, pyroelectric, acousto-optic properties and devices), (4) Guided wave materials and devices (fibers, waveguides, nonlinear effects and devices), (5) Optical information storage (optical storage, photorefraction, holographic storage), and (6) Optical communication (attenuation, dispersion, essential components, optical amplifiers, switching, etc.).

MS&E 703 Surfaces and Interfaces in Materials
Spring. 3 credits. Alternate years. J. M. Blakely.
This course deals with special topics in the field of surface and interface science. Some knowledge of basic statistical thermodynamics, crystallography, elementary quantum mechanics and theory of rate processes will be assumed. The following are the main topics: statistical thermodynamics of interfaces, morphological stability, atomic structure, energetics and structure determination, electronic structure of interfaces, charge and potential distributions, surface states, adsorption and segregation, atomic transport and growth processes at surfaces, oxidation and other surface reactions.

MS&E 779 Special Studies in Materials Sciences
Fall, spring. Variable credit. Offered on demand. Staff.
Supervised studies of special topics in materials science.

MS&E 798 Materials Science and Engineering Colloquium
Fall, spring. 1 credit each term. Credit limited to graduate students. Staff.
Lectures by visiting scientists, Cornell staff members, and graduate students on subjects

of interest in materials sciences, especially in connection with new research.

MS&E 799 Materials Science Research Seminars
Fall, spring. 2 credits each term. For graduate students involved in research projects. Staff.
Short presentations on research in progress by students and staff.

MS&E 800/801 Research in Materials Science
800, fall; 801, spring. Credit to be arranged. Staff.
Independent research in materials science under the guidance of a member of the staff.

MECHANICAL AND AEROSPACE ENGINEERING

General and Required Courses

M&AE 101 Naval Ship Systems
For description, see NAV S 202.

M&AE 102 Drawing and Engineering Design (also ENGRG 102)
Fall, spring. 1 credit. Half-term course offered twice each semester. Enrollment limited to thirty-two students each half term. Recommended for students without previous mechanical drawing experience. S-U grades optional.
For description, see ENGRG 102.

M&AE 117 Introduction to Mechanical Engineering (also ENGRI 117)
Fall or spring, to be determined. 3 credits.
For description, see ENGRI 117.

M&AE 212 Mechanical Properties and Processing of Engineering Materials (also MS&E 345)
Spring. 4 credits. Prerequisite: ENGRD 202.
Introduction to the broad range of mechanical behavior of materials and their processing. The mechanical properties of metals, ceramics, and composite materials are covered together with their microstructural features and processing. Ideal work methods are introduced for the analysis of bulk deformation processes. Heat treatment of metals and alloys, phase diagrams, casting and quenching processes.

M&AE 221 Thermodynamics (also ENGRD 221)
Fall, spring, may be offered summer. 3 credits. Prerequisites: MATH 192 and PHYS 112.
For description, see ENGRD 221.

M&AE 225 Mechanical Design and Synthesis
Spring. 3 credits. Prerequisite: ENGRD 202. Lab fee.
A hands-on laboratory, the use of machine tools, mechanical dissection, and a number of design projects provide direct experience of creative design synthesis.

M&AE 323 Introductory Fluid Mechanics
Fall. Usually offered in Engineering Cooperative Program. 4 credits. Prerequisites: ENGRD 202 and 203 and coregistration in 221, or permission of instructor.
Hydrostatics, conservation laws using control volume analysis and using differential analysis, Bernoulli's equation, potential flows, simple viscous flows (solved with Navier-Stokes equations), dimensional analysis, pipe flows, boundary layers, compressible flow.

M&AE 324 Heat Transfer
Spring; may also be offered in in Engineering Cooperative Program. 3 credits. Prerequisite: M&AE 323 or permission of instructor.
Conduction of heat in steady and unsteady situations. Surfaces with fins and systems with heat sources. Forced and natural convection of heat arising from flow around bodies and through ducts. Heat exchangers. Emission and absorption of radiation; radiative transfer between surfaces.

M&AE 325 Mechanical Design and Analysis
Fall; usually offered in Engineering Cooperative Program. 4 credits. Prerequisites: ENGRD 202, ENGRD 203, M&AE 212 and M&AE 225. Lab fee.
Application of the principles of mechanics and materials to problems of analysis and design of mechanical components and systems.

M&AE 326 System Dynamics
Spring; may be offered in Engineering Cooperative Program. 4 credits. Prerequisite: MATH 294, ENGRD 203. Junior standing required.
Dynamic behavior of mechanical systems: modeling, analysis techniques, and applications; vibrations of single- and multi-degree-of-freedom systems; feedback control systems, stability analysis. Computer simulation and experimental studies of vibration and control systems.

M&AE 427 Fluids/Heat Transfer Laboratory
Fall. 3 credits. Prerequisites: M&AE 323, 324. Fulfills the technical writing requirement.
Laboratory exercises in methods, techniques, and instrumentation used in fluid mechanics and the thermal sciences. Measurements of temperature, heat transfer, viscosity, drag, fluid-flow rate, effects of turbulence, air foil stall, two-phase flows and engine performance. Biweekly written assignments.

M&AE 428 Engineering Design
Fall. 2 credits. Prerequisite: completion of six semesters in mechanical engineering or equivalent.
Survey of design principles used in industry. Examples taken from all areas of mechanical engineering. Special emphasis on the design process as used in industry to solve practical problems. Case studies presented by engineers employed in industry and government. Students also participate in a design project.

Mechanical Systems, Design, Materials Processing, and Precision Engineering

M&AE 386 Automotive Engineering
Spring. 3 credits. Prerequisite: M&AE 325 or permission of instructor.
Selected topics in the analysis and design of vehicle components and vehicle systems. Emphasis on automobiles, trucks, and related vehicles. Power plant, drive line, brakes, aerodynamics, suspension, and structure. Other types of vehicles may be considered.

M&AE 389 Computer-Aided Design
Fall. 3 credits. Limited to juniors and seniors. May be offered in Engineering Cooperative Program. Fulfills computer applications requirement.
Course emphasizes the application of computers to the solution of mechanical engineering design problems. Topics include: geometry (space curves, splines, patches, solid modelling), computer graphics, and product rendering; analytical methods such as simulation, optimization, and curve fitting; and collaborative technologies such as the Web and computer supported collaborative work.

M&AE 412 Smash and Crash: Mechanics of Large Deformations
Prerequisites: MAE 212, T&AM 202.
Severe loading is a defining feature of both materials processing and crash worthiness. Materials intentionally are stressed beyond their elastic limits, resulting in deformations that are not reversible. In materials processing, the desire is to change the shape to manufacture components; in crash worthiness, it is to absorb the vehicle energy. In this course the fundamentals of plasticity are covered: yielding, flow laws, work hardening. Various solution methods, including bound theorems, are presented. The fundamentals are applied to localization, primary and secondary forming operations, and plastic buckling. Laboratory experiments deal with these topics and conclude with the individual design, construction, and testing of a crash cage.

[M&AE 417 Control of Robot Manipulators
Spring. 3 credits. Not offered 1997–98.
Introductory course in the analysis and control of mechanical manipulators. Topics include spatial descriptions and transformations, manipulator kinematics, inverse manipulator kinematics, differential relationships and static forces, manipulator dynamics, trajectory generation, sensors and actuators for manipulators, trajectory control, and compliant motion control. Various control strategies will be explored and analyzed, both graphically and mathematically, on a computer model of a simple manipulator.]

M&AE 455 Introduction to Composite Materials (also MS&E 455 and T&AM 455)
Spring. 4 credits.
For description, see T&AM 455.

M&AE 461 Entrepreneurship for Engineers (also ENGRG 461)
Spring. 3 credits. Enrollment open to seniors; others with permission of instructor. Enrollment may be limited.
Course will examine issues and skills necessary to identify, evaluate, and start new business ventures. Topics include: competitive analysis, competitive strategy; business formation; bookkeeping; technology protection; human resource management; negotiation; business valuation; and manufacturing issues. Guest speakers will provide a real-life perspective on critical issues facing the entrepreneur. A term project will be the team development of a business plan for an innovative new venture and will require detail of manufacturing, support, and information systems as well as staffing and cost data.

M&AE 464 Design for Manufacture
Spring. 3 credits. Prerequisites: M&AE 212 and M&AE 225. Fulfills field design requirement.
Readings and class discussion will provide a context for the importance of design for manufacture and assembly in product development, manufacturing and marketing. Lecture topics include DFMA design rules and applications; net present value analysis applied to product development; determination of manufacturing capability using statistical process control; and Taguchi design for experiment methodology to evaluate product/process improvements. A team design project will evaluate the manufacturability of a new or existing product.

M&AE 465 Biomechanical Systems—Analysis and Design
Spring. 3 credits. Prerequisites: ENGRD 202 and 203. Enrollment limited.
Selected topics from the study of the human body as a mechanical system. Emphasis on the modeling, analysis, and design of biomechanical systems frequently encountered in orthopaedic engineering and rehabilitation engineering.

M&AE 467 Advanced Mechanical Analysis and Design
Fall. 3 or 4 credits. Evening examinations. Prerequisite: M&AE 325 and M&AE 326 or permission of instructor.
Further application of the principles of mechanics and materials to problems of analysis and design of mechanical components and systems. Diverse examples from aerospace, automotive, and biomechanical fields, with emphasis on current machinery applications. Students have access to general-purpose software tools (such as MATLAB) as well as specialized computational codes (such as ANSYS) for analysis of stress and deformation. Term project.

M&AE 469 Stress Analysis for Mechanical and Aerospace Design
Fall. 3 credits. Prerequisites: T&AM 202 and M&AE 325 or permission of instructor. Evening examinations.
Study of advanced topics in the analysis of stress and deformation of elastic bodies, with applications to analysis and design of mechanical and aerospace systems and components. Review of mechanics fundamentals and their application to classical problems. Introduction to modern computational methods (such as the finite element method) for analysis of stress and deformation.

M&AE 478 Feedback Control Systems
For description, see ELE E 471.

M&AE 486 Automotive Engineering Design
Spring. 4 credits. Prerequisite: M&AE 428 and senior standing. Fulfills field design requirement.
For description, see M&AE 386.

M&AE 489 Computer-Aided Design Project
Fall. 4 credits. Limited to seniors in mechanical engineering. Fulfills both field design and computer applications requirements.
Requires extensive project in addition to course assignments. For description, see M&AE 389.

M&AE 511 Survey of Manufacturing Processes
Fall or spring to be determined; may be offered in summer program. 3 credits. Prerequisites: graduate standing or permission of instructor. Not for M&AE majors.
Yield criteria and plastic flow. Manufacturing processes for engineering materials, including metals, polymers, ceramics and composites. Casting, forming, material removal and joining processes. Intended for non-mechanical engineers.

M&AE 514 Introduction to Precision Engineering
Fall. 3 credits or 4 with laboratory. Prerequisites: ENGRG 102 and M&AE 212, or 412, or permission of instructor.
Variability in mechanical products arises primarily from the processes used to make and assemble parts; it must be accommodated in design and controlled in manufacturing. This course addresses *form* variability through studies of ideal-form modeling, form tolerancing, form measurement, and manufacturing process modeling (sources of form error). Central principles, practices, and limitations are summarized.

M&AE 570 Intermediate Dynamics
Fall. 3 credits. Prerequisites: graduate standing or permission of instructor. 2 lecs.
Introduction to analytical mechanics, virtual work, Lagrangian mechanics. Small vibration and stability theory. Newtonian-Eulerian mechanics of rigid bodies.

[M&AE 577 Vibrations and Waves in Elastic Systems (also T&AM 574)
Not offered 1997–98.
For description, see T&AM 574.]

[M&AE 578 Feedback Control Systems Design and Implementation
Spring. 3 credits. Prerequisite: M&AE 478 or ELE E 471, graduate standing, or permission of instructor. Fulfills the computer application requirement. Not offered 1997–98.
Further development of the theory, design, and implementation of feedback control systems with particular emphasis on applications, modeling and system identification, and hardware implementation. Digital control is introduced. Labs include real-time microprocessor-based control of a D.C.-motor positioning system, a two-link robot arm, and a two-tank level-control system.]

M&AE 612 Materials Processing: Theory and Applications
Fall. 4 credits. Prerequisite: graduate standing, or permission of instructor.
Basic principles governing the inelastic behavior of solids. Slab-analysis models and bound theorems for problems of forging, extrusion, and rolling. Analysis of sheet-metal forming including limit diagrams and springback. Defect initiation during forming processes. Basic solidification processes. Morphological instability of a solid/liquid interface, solidification microstructures, solute redistribution, microsegregation and macrosegregation. Thermomechanical defects in casting processes. Rapid solidification microstructures. Behavior and forming of metal alloys in the semisolid state.

M&AE 613 Computational Methods in Materials Processing
Spring. 4 credits. Prerequisite: M&AE 612 or permission of instructor.
Thermodynamic framework for inelastic constitutive models, temperature and rate dependence, phenomenology of plastic deformation. The finite-element method for rigid plastic flow analysis of extrusion, drawing, forging, rolling and plate bending. Integration of viscoplastic models, geometry updating, boundary conditions, friction at tool/workpiece interface, modeling of incompressibility, iterative process, and applications to process design. Comparison of the flow formulation with an elasto-plastic analysis. Analysis of hot forming processes. Procedures for heat-transfer analysis. Preform design. Modeling of plastic anisotropy with applications to sheet forming. Modeling of heat flow and deformation on casting processes.

M&AE 615 Experiments in Materials Processing
Fall. 4 credits. Prerequisite: graduate standing or permission of instructor.
This course will focus on experiments related to the mechanical properties of materials and experiments using various materials processing apparati and will include a general introduction to sensors and instrumentation for engineering measurements. Testing for mechanical properties/model parameter characterization: inelastic deformation, fatigue, and fracture, including rate and temperature effects. Process simulation experiments including forging, extrusion, rolling, and ironing. Formability experiments. Determination of heat transfer coefficients associated with quenching and solidification process. Fluidity measurements. Specimen design and fabrication. Although the focus is on metals and alloys attention is also given to polymers and ceramic materials.

M&AE 625 Product Development
Spring. 4 credits. Prerequisite: graduate standing.
Emphasis will be placed on the Product Realization Process for products based on advanced technologies and requiring concurrent engineering. Covers a wide range of methods and techniques used in the product development process: concurrent engineering, team organization, technologies to support collaboration, cognitive models of design, generation of product specifications, quality function deployment, conceptual design, configuration design, FAST/FMEA, and parametric design.

M&AE 655 Composite Materials (also MS&E 655 and T&AM 655)
Spring. 4 credits.
For description, see T&AM 655.

[M&AE 665 Advanced Topics in Orthopaedic Biomechanics
On demand. 4 credits. Prerequisites: graduate standing, prior or concurrent registration in advanced courses in strength of materials or elasticity, and intermediate dynamics. Not offered 1997–98.
Advanced treatment of topics in the biomechanics of the musculoskeletal system. Force analysis of the musculoskeletal system under static and dynamic conditions, compact and trabecular bone as structural materials, structural analysis of bone-implant systems, remodeling of bone.]

M&AE 670 Finite Element Analysis for Mechanical and Aerospace Design
Spring. 4 credits. Prerequisite: graduate standing, or permission of instructor. Evening examinations.
Introduction to the finite-element method for static and dynamic analysis of mechanical and aerospace structures (and related nonstructural applications such as heat conduction). Primary emphasis on underlying mechanics and numerical methods. Secondary consideration of inherent capabilities and limitations of large-scale, general-purpose structural mechanics programs (such as ANSYS). Introduction to computational aspects through study of small, special-purpose programs and application of available general-purpose programs. Term project.

M&AE 677 Advanced Topics in Systems and Control
Spring. 4 credits. Prerequisite: M&AE 478 (ELE E 471), ELE E 521, graduate standing, or permission of instructor.
Modern topics in model based control pertaining to multi-input, multi-output systems. Emphasis on design techniques which result in closed loop systems that are insensitive to modeling errors. Topics include H-infinity and H-2 optimization, explicit models of uncertainty, gain scheduling, and the analysis of uncertain systems. Computer-aided design laboratory will include aerospace applications such as flight control, control of flexible space structures, and other topics depending on class interest.

[M&AE 678 Optimal Control and Estimation
Fall, on demand. 3 credits. Prerequisite: M&AE 478, ELE E 471, graduate standing, or permission of instructor; programming ability in FORTRAN, Pascal, or C. Corequisite: ELE E 521. Not offered 1997–98.
Develops the theory of the design of modern multi-input–multi-output feedback control systems using optimal control techniques. Topics covered include trajectory optimization and the minimum principle, bang-bang optimal control solutions, Kalman filtering, LQR/LQE compensator design, suboptimal control and estimation, and applications to regulator and tracking problems. Both linear and nonlinear systems, and continuous-time and discrete-time control, and considered.]

M&AE 679 Modeling and Simulation of Dynamic Systems
Spring. 4 credits. Prerequisite: graduate standing or permission of instructor.
Selected applications from diverse fields. Representation of continuous dynamic systems by state-variable models. Simulation by numerical integration using general-purpose languages (such as MATLAB) and simulation packages. Special topics in linear and nonlinear dynamics. Term project.

M&AE 680 Finite Element Analysis for Mechanical, Structural, and Aerospace Applications (also CEE 772 and T&AM 666)
Spring. 3 credits. Prerequisite: T&AM 663
Conceptual, theoretical, and practical bases for finite element analysis in solid and structural mechanics, such as the bending of beams, torsion of shafts, and two-dimensional elasticity. Topics include the methodology for obtaining a discretized system of equations from differential equations via weighted residuals, consistent application of boundary conditions, various types of elements including isoparametric elements, numerical integration of elemental quantities, error estimation, and (adaptive) mesh generation. Programming assignments using Matlab and C codes provided by the instructor.

[M&AE 715 Finite-Deformation Plasticity and Rheology and Their Applications in Materials Processing
Fall. 4 credits. Prerequisites: advanced graduate students, Introduction to Continuum Mechanics and Plasticity. Offered alternate years. Not offered 1997–98.
Hyperelasticity and hypoelasticity. Phenomenology of rate-dependent plastic deformation. Kinematic framework for inelastic constitutive modeling. Lagrangian and Eulerian FEM formulations for large deformation elastoviscoplastic problems. Viscoplasticity coupled with damage. Slip systems and lattice rotation. Texture development and strain hardening in rate-dependent polycrystals. Modeling of the evolution of deformation-induced crystallographic texture in forming processes. Rheological models for polymers.]

Energy, Fluids, and Aerospace Engineering

M&AE 305 Introduction to Aeronautics
Fall. 3 credits. Limited to upperclass engineers; others with permission of instructor.
Introduction to the concept of aircraft design. Principles of incompressible and compressible aerodynamics, boundary layers, and wing theory. Description and performance of propeller-driven and jet propulsion engines. Design studies focus on transonic passenger airplanes and small supersonic jets.

M&AE 306 Spacecraft Engineering
Spring. 3 credits. Upperclass engineering students.
Introduction to spacecraft design from launch, through orbital operation, to reentry. Topics covered include space missions, space environment, orbital mechanics, rocket theory, and reentry. Emphasis on satellites orbiting the Earth. Several guest lectures on current problems and trends in spacecraft operation and development.

M&AE 400 Components and Systems: Engineering in a Social Context (also S&TS 400)
Spring. 3 credits. Prerequisites: upperclass standing, two years of college physics. Serves as an approved elective but not as a field elective in mechanical engineering. Offered alternate years.
This course addresses, at a technical level, broader questions than are normally posed in the traditional engineering or physics curriculum. Through the study of individual cases such as the Strategic Defense Initiative (SDI), supersonic transport, and the automobile and its effect on the environment, we investigate interactions between the scientific, technical, political, economic, and social forces that are involved in the development of engineering systems.

M&AE 401 Components and Systems: Engineering in a Social Context
Spring. 4 credits. Prerequisites: senior standing, two years of college physics. Fulfills field design requirement. Offered alternate years.
For description, see M&AE 400.

M&AE 423 Intermediate Fluid Dynamics
Spring. 3 credits. Prerequisite: M&AE 323.
This course builds on the foundation of M&AE 323. Emphasis will be both on the calculation of real flows (both engineering and environmental) and fundamental principles. Topics covered will include some exact solutions to the Navier-Stokes equations, boundary layers, wakes and jets, separation, convection, stratified and rotating flows, fluid instabilities, turbulence and chaos.

M&AE 449 Combustion Engines
Spring. 3 credits. Prerequisites: ENGRD 221 and M&AE 323.
Introduction to combustion engines, with emphasis on the application of thermodynamic and fluid-dynamic principles affecting their performance. Air-standard analyses, chemical equilibrium, ideal-cycle analyses, deviations from ideal processes, combustion knock. Formation and control of undesirable exhaust emissions.

M&AE 458 Introduction to Nuclear Science and Engineering I (also A&EP 303, and NS&E 403)
For description, see NS&E 403.

M&AE 459 Introduction to Controlled Fusion: Principles and Technology (also ELE E 484)
For description, see NS&E 484.

M&AE 506 Aerospace Propulsion Systems
Spring. 3 credits. Prerequisite: M&AE 323 or permission of instructor. Offered alternate years. Offered 1997–98.
Application of thermodynamic and fluid-mechanic principles to design and performance of aerospace systems. Jet propulsion principles, including rockets. Electric propulsion. Future possibilities for improved performance.

[M&AE 507 Dynamics of Flight Vehicles
Spring. 3 credits. Prerequisites: M&AE 305 and M&AE 323 or permission of instructor. Offered alternate years. Not offered 1997–98.
Introduction to stability and control of atmospheric-flight vehicles. Review of aerodynamic forces and methods for analysis of linear systems. Static stability and control. Small disturbance equations of unsteady motion. Dynamic stability of longitudinal and lateral-directional motions; transient response. At the level of *Dynamics of Flight: Stability and Control* by Etkin.]

M&AE 543 Combustion Processes
Fall. 3 credits. Prerequisite: graduate standing or permission of instructor.
An introduction to combustion and flame processes, with emphasis on fundamental fluid dynamics, heat and mass transport, and reaction-kinetic processes that govern combustion rates. Thermochemistry, kinetics, vessel explosions, laminar and turbulent premixed and diffusion flames, droplet combustion, and combustion of solids.

M&AE 601 Foundations of Fluid Dynamics and Aerodynamics
Fall. 4 credits. Prerequisite: graduate standing or permission of instructor.
Foundations of fluid mechanics from an advanced viewpoint. Aspects of kinetic theory as it applies to the formulation of continuum fluid dynamics. Surface phenomena and boundary conditions at interfaces. Fundamental kinematic descriptions of fluid flow, tensor analysis, derivation of the Navier-Stokes equations and energy equation for compressible fluids. Viscous flows, boundary layers, potential flows, vorticity dynamics.

M&AE 602 Fluid Dynamics at High Reynolds Numbers
Spring. 4 credits. Prerequisite: M&AE 601.
Navier-Stokes and Euler equations, integral formulas for fluid forces and moments on immersed bodies in compressible and incompressible viscous flows. Vorticity dynamics in compressible flows, Kelvin's theorem. Fjortoft's theorem, Helmholtz decomposition of vector fields. Singularities, vortex filaments, vortex sheets, Biot-Savart relations. Irrotational motion: representations in terms of velocity or vector potentials. Topology of flows; general results in potential theory.

M&AE 603 Compressible Gas Dynamics
Fall. 4 credits. Graduate standing or permission of instructor.
Fundamentals of compressible gas dynamics are described using thermodynamics and fluid properties. Isentropic flow theory. Normal shock waves including Rankine-Hugoniot relations. Duct flows including effects of area, friction, and heat interaction. Oblique shock waves and Prandtl-Meyer expansion fans. Applications include high-speed aerodynamics, combustor design, and jets used for materials processing.

M&AE 608 Physics of Fluids
Spring. 4 credits. Prerequisite: graduate standing or permission of instructor.
Behavior of a gas is considered at the microscopic level. Introduction to kinetic theory: velocity distribution, collisions, Boltzmann equation. Quantum theory: postulates of quantum mechanics, internal structure, rigid rotator, harmonic oscillator, one-electron atom. Statistical mechanics: partition functions, relation to thermodynamics, calculations of thermodynamic properties. Chemical rate processes.

M&AE 636 Elements of Computational Aerodynamics
Spring. 4 credits. Prerequisites: graduate standing and a graduate-level course in fluid mechanics.
Topics relevant to numerical solution of problems in aerodynamics and fluid mechanics. Analysis and application of computational techniques appropriate for solution of inviscid or high Reynolds number fluid flow problems. Course has common lectures with M&AE 736, but is more applications oriented and uses commercial software for all computational exercises.

M&AE 651 Advanced Heat Transfer
Fall. 4 credits. Prerequisite: graduate standing or permission of instructor.
Advanced treatment of conductive and convective heat transfer. Basic equations reasoned in detail. Integral and differential formulations. Exact and approximate solutions. Forced convection. Natural convection. Laminar and turbulent flows. Effects of viscous dissipation and mass transfer.

M&AE 654 Radiation Heat Transfer
2–4 credits. Prerequisite: graduate standing or permission of instructor.
An independent readings course. Coverage of surface- and gas-radiation properties, including reflection, emission, absorption, and scattering. Deductions from the first and second laws of thermodynamics. The radiative-transfer equation; surface-surface, surface-volume, and volume-volume exchange. Simplifying approximations. Modern methods for exchange calculations and transport analysis including integral, computer-graphics-assisted, and Monte Carlo approaches. Assigned readings from *Radiative Heat Transfer,* by Modest. Discussion sessions. Assigned problems and papers.

M&AE 732 Analysis of Turbulent Flows
Spring. 4 credits. Prerequisite: M&AE 601 or permission of instructor. Offered alternate years. Offered 1997–98.
Study of methods for calculating the properties.of turbulent flows. Characteristics of turbulent flows. Direct numerical simulations, large-eddy simulations, and the closure problem. Reynolds-stress equation: effects of dissipation, anisotropy, deformation. Transported scalars. Probability density functions (pdf's): definitions and properties, transport equations, relationship to second-order closures, stochastic modeling, Langevin equation, and Monte Carlo solutions. The course emphasizes comparison of theory with experiment.

M&AE 733 Stability of Fluid Flow
Fall, on demand. 4 credits. S-U grades only. Prerequisite: graduate standing or permission of instructor.
Basic stability and bifurcation theory in fluid systems. Thermal, double-diffusive, and related instabilities. Post-bifurcation behavior: the Ginzburg-Landau (Stewartson-Stuart) and Chapman-Proctor-Sivashinsky amplitude equations. Phase dynamics and pattern formation. Stability of periodic motion: Floquet theory. Secondary instabilities; Eckhaus instability, Busse "balloons." Energy stability theory. Effects of symmetry. Taylor-Couette instability. "Open" flow systems: inviscid Kelvin-Helmholtz, Rayleigh-Taylor instability, and capillary instability of liquid jets. Stability of parallel shear flows and of concentrated vortex flows. Spatial development of linearly unstable motion: "absolute" and "convective" instability.

[M&AE 734 Turbulence and Turbulent Flow
Fall. 4 credits. Prerequisite: M&AE 601, graduate standing, or permission of instructor. Not offered 1997–98.
Topics include the dynamics of buoyancy and shear-driven turbulence, boundary-free and bounded shear flows, second-order modeling, the statistical description of turbulence, turbulent transport, and spectral dynamics.]

M&AE 736 Theory of Computational Aerodynamics
Spring. 4 credits. Prerequisites: graduate standing, an advanced course in continuum mechanics or fluid mechanics, and some FORTRAN programming experience.
Numerical methods to solve inviscid and high-Reynolds-number fluid-dynamics problems, including finite-difference, finite-volume, and surface-singularity methods. Accuracy, convergence, and stability; treatment of boundary conditions and grid generation. Focus on hyperbolic (unsteady flow with shock waves) and mixed hyperbolic-elliptic (steady transonic flow) problems. Assignments require programming a digital computer.

M&AE 737 Computational Fluid Mechanics and Heat Transfer
Fall. 4 credits. Prerequisites: graduate standing; an advance course in continuum mechanics, heat transfer, or fluid mechanics; and some FORTRAN, C, or C++ programming experience.
Numerical methods for elliptic and parabolic partial differential equations arising in fluid flow and heat-transfer problems involving convection and diffusion. Finite-difference, finite-volume, and some spectral methods. Accuracy, stability, convergence, and conservation. Review of current methods. Emphasis on steady and unsteady incompressible flows. Assigned problems are solved on a digital computer.

Special Offerings

M&AE 490 Special Investigations in Mechanical and Aerospace Engineering
Fall, spring. Credit to be arranged. Limited to undergraduate students. Prerequisite: permission of instructor.
Intended for an individual student or a small group of students who want to pursue a particular analytical or experimental investigation outside of regular courses or for informal instruction supplementing that given in regular courses.

M&AE 491 Design Projects in Mechanical and Aerospace Engineering
Fall, spring. Credits to be arranged. Prerequisite or corequisite: M&AE 428. Fulfills field design requirement.
Intended for individual students or small groups of students who want to pursue particular design projects outside of regular courses.

M&AE 545 Energy Seminar
For description, see ELE E 587.

M&AE 592 Seminar and Design Project in Aerospace Engineering
Fall, spring. 2 credits each term. Prerequisite: graduate standing or permission of instructor. Intended for students in M.Eng.(Aerospace) program.
Introduction to topics of current research interest in aerospace engineering by Aerospace faculty and invited speakers. Individual design projects supervised by separate faculty members after introductory sessions.

M&AE 594 Manufacturing Seminar
For description, see OR&IE 893.

M&AE 690 Special Investigations in Mechanical and Aerospace Engineering
Fall, spring. Credit to be arranged. Limited to graduate students.

M&AE 695 Special Topics in Mechanical and Aerospace Engineering
Fall, spring. Credit to be arranged. Graduate standing and permission of instructor.

Special lectures by faculty members on topics of current research.

M&AE 791 Mechanical and Aerospace Research Conference
Fall, spring. 1 credit each term. S-U grades only. For graduate students involved in research projects.
Presentations on research in progress by faculty and students.

M&AE 799 Mechanical and Aerospace Engineering Colloquium
Fall, spring. 1 credit each term. Credit limited to graduate students. All students and staff invited to attend.
Lectures by visiting scientists and Cornell faculty and staff members on research topics of current interest in mechanical and aerospace science, especially in connection with new research.

M&AE 890 Research in Mechanical and Aerospace Engineering
Credit to be arranged. Prerequisite: candidacy for M.S. degree in mechanical or aerospace engineering or approval of director.
Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the faculty.

M&AE 990 Research in Mechanical and Aerospace Engineering
Credit to be arranged. Prerequisite: candidacy for Ph.D. degree in mechanical or aerospace engineering or approval of director.
Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the faculty.

NUCLEAR SCIENCE AND ENGINEERING

A number of courses in nuclear science and engineering are offered through the School of Applied and Engineering Physics (see A&EP 609, 612, 633, 638, and 651).

NS&E 121 Fission, Fusion, and Radiation (also ENGRI 121)
Spring. 3 credits.
This is a course in the Introduction to Engineering series. For description, see ENGRI 121.

NS&E 285 Art, Archaeology, and Analysis (also ARKEO 285, ART 372, ENGRI 185, MS&E 285 and PHYS 200)
For description, see ENGRI 185.

NS&E 403 Introduction to Nuclear Science and Engineering I (also A&EP 403, and M&AE 458)
Fall. 3 credits. Prerequisite: Physics 214 and Mathematics 294. This course is designed for juniors or seniors from any engineering field who want to prepare for graduate-level nuclear science and engineering courses at Cornell or elsewhere. It can also serve as a basic course for those who do not intend to continue in the field.
Introduction to the fundamentals of nuclear reactors. Topics include an overview of the field of nuclear engineering; nuclear structure, radioactivity, and reactions; interaction of radiation and matter; and neutron moderation, neutron diffusion, the steady-state chain reaction, and reactor kinetics. At the level of *Introduction to Nuclear Engineering*, by Lamarsh.

NS&E 484 Introduction to Controlled Fusion: Principles and Technology (also ELE E 484, and A&EP 484)
Spring. 3 credits. Prerequisites: PHYS 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics; and permission of instructor. Intended for seniors and graduate students.
Introduction to the physical principles and various engineering aspects underlying power generation by controlled fusion. Topics include: (i) fuels and conditions required for fusion power, and basic fusion-reactor concepts; (ii) fundamental aspects of plasma physics relevant to fusion plasmas, and basic engineering problems for a fusion reactor; and (iii) an engineering analysis of proposed magnetic and/or intertial confinement fusion-reactor designs.

NS&E 509 Nuclear Physics for Applications (also A&EP 609)
Fall. 3 credits. Prerequisites: sophomore physics and math, or permission of instructor; some upper-division physics is desirable. Primarily for graduate students, especially those with a major or minor in Nuclear Science and Engineering; also open to qualified undergraduates. Offered on demand.
A first course in nuclear physics. Systematic presentation of nuclear phenomena and processes that underlie applications ranging from nuclear power (fission and fusion), to nuclear astrophysics, to nuclear analytical methods for research in nonnuclear fields. Radioactivity, nuclear reactions, and interaction of radiation with matter. At the level of *Radiochemistry and Nuclear Methods of Analysis,* by Ehmann and Vance.

[NS&E 545 Energy Seminar (also M&AE 545 and ELE E 587)
Not offered 1997–98.
For description, see ELE E 587.]

NS&E 551 Nuclear Methods in Non-Nuclear Research Fields
Spring. 3 credits. Prerequisite: PHYS 214 or 218, or permission of instructor; some upper-division physics desirable. Primarily for graduate students in archaeology, geology, chemistry, biology, materials science, and other non-nuclear fields in which nuclear methods are used. Open to qualified undergraduates. A more intensive related course, A&EP 651, is intended for nuclear specialists. Offered on demand.
Lectures on interaction of radiation with matter, radiation protection, and nuclear instruments. Experiments on radiation detection and measurement; electronic instrumentation, including computerized systems; activation analysis; and emerging applications such as prompt gamma analysis and neutron radiography. The TRIGA reactor is used. Emphasis is on methods used in non-nuclear fields. At the level of *Radiochemistry and Nuclear Methods of Analysis*, by Ehmann and Vance.

NS&E 590 Independent Study
Fall, spring. 1–4 credits. Grade option letter or S-U.
Independent study or project under guidance of a faculty member.

NS&E 591 Project
Fall, spring. 1–6 credits.
Master of Engineering or other project under guidance of a faculty member.

NS&E 621 Radiation Effects in Microelectronics (also ELE E 633)
Fall. 1 to 3 credits. Prerequisite: ELE E 435 or permission of instructor. A seminar offered in alternate years intended for seniors and graduate students in engineering or applied physics. S-U or letter grade option.
An introduction to the physical processes that underlie the malfunction and failure of microelectronic circuitry resulting from exposure to ionizing radiation. The roles testing and modeling play in improving circuit and device designs are included.

OPERATIONS RESEARCH AND INDUSTRIAL ENGINEERING

OR&IE 115 Engineering Application of Operations Research (also ENGRI 115)
Fall, spring. 3 credits. Enrollment not open to OR&IE upperclass majors.
For description see ENGRI 115.

OR&IE 270 Basic Engineering Probability and Statistics (also ENGRD 270)
Fall, spring, summer. 3 credits. Pre- or co-requisite: MATH 293.
For description see ENGRD 270.

OR&IE 310 Industrial Systems Analysis
Spring. 4 credits. Pre or co-requisite: ENGRD 270.
Design of production facilities, including engineering economy, taxation effects, materials handling process design, and facility layout. Operations analysis, including process scheduling, process evaluation, procedural analysis, project management, methods analysis and design, work measurement, inventory control, job evaluation, and quality engineering and control. Formerly listed as OR&IE 410.

OR&IE 320 Optimization I
Fall. 4 credits. Prerequisite: MATH 221 or 294.
Formulation of linear programming problems and solution by the simplex method. Related topics such as sensitivity analysis, duality, and network programming. Applications include such models as resource allocation and production planning.

OR&IE 321 Optimization II
Spring. 4 credits. Prerequisite: OR&IE 320 or equivalent.
A variety of optimization methods stressing extensions of linear programming and its applications but also including topics drawn from integer, dynamic, and nonlinear programming. Formulation and modeling are stressed as well as numerous applications.

OR&IE 350 Financial and Managerial Accounting
Fall. 4 credits.
Principles of accounting, financial reports, financial-transactions analysis; financial-statement analysis, budgeting, job-order and process-cost systems, standard costing and variance analysis, economic analysis of short-term decisions.

OR&IE 360 Engineering Probability and Statistics II

Fall. 4 credits. Prerequisite: ENGRD 270 or equivalent.

This second course in probability and statistics provides a rigorous foundation in theory combined with the methods for modeling, analyzing, and controlling randomness in engineering problems. Probabilistic ideas are used to construct models for engineering problems, and statistical methods are used to test and estimate parameters for these models. Specific topics include random variables, probability distributions, density functions, expectation and variance, multidimensional random variables, and important distributions including normal, Poisson, exponential, hypothesis testing, confidence intervals, and point estimation using maximum likelihood and the method of moments.

OR&IE 361 Introductory Engineering Stochastic Processes I

Spring. 4 credits. Prerequisite: OR&IE 360 or equivalent.

Basic concepts and techniques of random processes are used to construct models for a variety of problems of practical interest. Topics include the Poisson process, Markov chains, renewal theory, models for queuing and reliability.

OR&IE 416 Design of Manufacturing Systems

Fall. 4 credits. Senior OR&IE students only. Others by permission of instructor only.

Project course in which students, working in teams, design a manufacturing logistics system and conduct capacity, material flow, and cost analysis of their design. Meetings between project teams and faculty advisers are substituted for some lectures. Analytical methods for controlling inventories, planning production, and evaluating system performance will be presented in lectures. Lab fee $15.

OR&IE 417 Material Handling Systems

Fall. 4 credits.

Design of the layout of processes and storage areas and the material-handling system for movement of items. Typical equipment used. Material flow analysis. The functions of identification control, storage, movement, batching, merging, and dispersion.

[OR&IE 431 Discrete Models

Fall. 4 credits. Prerequisites: OR&IE 320 and COM S 211, or permission of instructor. Not offered 1997–98, next offered 1998–99.

Basic concepts of graphs, networks, and discrete optimization. Fundamental models and applications, and algorithmic techniques for their analysis. Specific optimization models studied include flows in networks, the traveling salesman problem, and network design.]

OR&IE 432 Nonlinear Optimization

Spring. 4 credits. Prerequisite: OR&IE 320.

Introduction to the practical and theoretical aspects of nonlinear optimization. Attention given to the computational efficiency of algorithms and the application of nonlinear techniques to linear programming; e.g., interior-point methods. Methods of numerical linear algebra introduced as needed.

OR&IE 435 Introduction to Game Theory

Spring. 3 credits.

A broad survey of the mathematical theory of games, including such topics as two-person matrix and bimatrix games; cooperative and noncooperative n-person games; games in extensive, normal, and characteristic function form. Economic market games. Applications to weighted voting and cost allocation.

OR&IE 451 Economic Analysis of Engineering Systems

Spring. 4 credits. Prerequisites: OR&IE 320 and OR&IE 350.

Financial planning, including cash-flow analysis and inventory flow models. Engineering economic analysis, including discounted cash flows and taxation effects. Application of optimization techniques, as in equipment replacement or capacity expansion models. Issues in designing manufacturing systems. Student group project.

[OR&IE 462 Introductory Engineering Stochastic Processes II

Spring. 4 credits. Prerequisite: OR&IE 361 or equivalent. Not offered 1997–98, next offered 1998–99.

Stationary processes, martingales, random walks, and gambler's ruin problems, processes with stationary independent increments, Brownian motion and other cases, branching processes, renewal and Markov-renewal processes, reliability theory, Markov decision processes, optimal stopping, statistical inference from stochastic models, and stochastic comparison methods for probability models. Applications to population growth, spread of epidemics, and other models.]

OR&IE 475 Regression

Spring. First half of term. 2 credits. Prerequisite: ENGRD 270.

Linear models; estimation and testing; confidence sets; diagnostics and residual analysis; variable selection and modeling.

OR&IE 476 Experimental Design I

Spring. Second half of term. 2 credits. Prerequisite: OR&IE 475.

Experimental design to improve industrial products and manufacturing processes. Randomization. Blocking. Fractional factorials. Orthogonal arrays. Nested designs.

OR&IE 490 Teaching in OR&IE

Fall, spring. Credit to be arranged. Prerequisite: permission of instructor.

This course involves working as a TA in an OR&IE course. The course instructor will assign credits (the guideline is 1 credit per 4 hours/week of work with a limit of 3 credits).

OR&IE 499 OR&IE Project

Fall, spring. Credit to be arranged. Prerequisite: permission of instructor.

Project-type work, under faculty supervision, on a real problem existing in some firm or institution, usually a regional organization. Opportunities in the course may be discussed with the associate director.

OR&IE 515 Design of Manufacturing Systems

Fall. 4 credits. Prerequisite: permission of instructor. Limited to graduate students in Engineering and the Business School.

For description, see OR&IE 416. Lab fee $15.

OR&IE 516 Case Studies

Fall. 1 credit. Limited to M.Eng. students in OR&IE.

Students are presented with unstructured problems that resemble real-world situations. They work in project groups to formulate mathematical models, perform computer analyses of the data and models, and present oral and written reports.

OR&IE 520 Operations Research I: Optimization I

For description, see OR&IE 320.

OR&IE 521 Optimization II

For description, see OR&IE 321.

OR&IE 522 Operations Research I: Topics in Linear Optimization

Fall. 1 credit. Corequisite: OR&IE 520. Students who have already taken OR&IE 321 or 521 should not enroll. Limited to M.Eng. students in OR&IE.

An extension of OR&IE 520 that deals with applications and methodologies of dynamic programming, integer programming, and large-scale linear programming.

OR&IE 523 Operations Research II: Introduction to Stochastic Processes I

For description, see OR&IE 361.

[OR&IE 525 Production Planning and Scheduling Theory and Practice

Spring. 3 credits. Prerequisite: OR&IE 320. Not offered 1997–98, next offered 1998–99.

Production planning, including MRP, linear programming, and related concepts. Scheduling and sequencing work in manufacturing systems. Job release strategies and control of work in process inventories. Focus on setup time as a determinant of plans and schedules.]

OR&IE 528–529 Selected Topics in Applied Operations Research

Fall, spring. Credit to be arranged. Prerequisite: permission of instructor.

Current topics dealing with applications of operations research.

OR&IE 551 Economic Analysis of Engineering Systems

Spring. 4 credits. Prerequisites: OR&IE 320 and OR&IE 350.

Lectures concurrent with OR&IE 451. For description see OR&IE 451.

OR&IE 560 Engineering Probability and Statistics II

For description, see OR&IE 360.

OR&IE 561 Queuing Theory and Its Applications

Fall. 3 credits. Prerequisite: OR&IE 361 or permission of instructor.

Basic queuing models. Little's Law, PASTA property, Markovian and non-Markovian queues. Optimization of queues. Polling queues: exhaustive and gated service. Jackson queuing networks. Open networks and closed networks. Product-form queuing networks.

OR&IE 562 Inventory Theory

Spring. 4 credits. Prerequisite: OR&IE 321, 361, 416 or permission of instructor.

The first portion of this course is devoted to the analysis of several deterministic and probabilistic models for the control of single and multiple items at one of many locations. The second portion of this course is presented in an experiential learning format. The focus is on analyzing and designing an integrated production and distribution system for a global company. Applications are stressed throughout.

[OR&IE 563 Applied Time-Series Analysis

Fall. 3 credits. Prerequisites: OR&IE 361 and OR&IE 270, or permission of instructor. Not offered 1997–98, next offered 1998–99.

The first part of this course treats regression methods to model seasonal and non-seasonal data. After that, Box-Jenkins models, which are versatile, widely used, and applicable to nonstationary and seasonal time series, are covered in detail. The various stages of model identification, estimation, diagnostic checking, and forecasting are treated. Analysis of real data is carried out. Assignments require computer work with a time-series package.]

[OR&IE 564 Introductory Engineering Stochastic Processes II

Spring. 4 credits. Prerequisite: OR&IE 361 or equivalent. Lectures concurrent with OR&IE 462. Not offered 1997–98; next offered 1998–99.

For description, see OR&IE 462.]

OR&IE 565 Applied Financial Engineering

Spring. 4 credits. Limited to M.Eng. students.

This course has two components: a sequence of lectures and a project. The course will be co-listed with the Johnson School and will be co-taught by one faculty member from each school. The lectures will be given by the faculty for the course and by invited speakers from the financial industry. The project will satisfy the M.Eng. project requirement.

OR&IE 567 Semester in Manufacturing Management (also NBA 650)

Spring. 15 credits. Enrollment limited. Permission of instructor required.

For description, see NBA 650.

[OR&IE 575 Experimental Design II

Spring. Last half of term. 2 credits. Prerequisite: OR&IE 476. Not offered 1997–98. To be offered 1998–99.

Continuation of OR&IE 476. Design of industrial experiments. Response surfaces. Robust product designs. Taguchi's methods.]

OR&IE 577 Quality Control

Fall. 3 credits. Prerequisites: ENGRD 270.

Concepts and methods for process and acceptance control. Control charts for variables and attributes. Process capability analysis. Acceptance sampling. Continuous sampling plans. Life tests. Use of experimental design and Taguchi methods for off-line control.

OR&IE 580 Design and Analysis of Simulated Systems

Fall. 4 credits. Prerequisites: programming experience and OR&IE 360/560, or permission of instructor. Note: OR&IE 360/560 may be taken concurrently.

Digital computer programs to simulate the operation of complex discrete systems in time. Modeling, program organization, pseudo–random-variable generation, simulation languages, statistical considerations; applications to a variety of problem areas.

OR&IE 599 Project

Fall, spring. 5 credits. For M.Eng. students.

Identification, analysis, design, and evaluation of feasible solutions to some applied problem in the OR&IE field. A formal report and oral defense of the approach and solution are required.

[OR&IE 625 Scheduling Theory

Spring. 3 credits. Not offered 1997–98; next offered 1998–99.

Scheduling and sequencing problems, including single-machine problems, parallel-machine scheduling, and shop scheduling. The emphasis is on the design and analysis of polynomial time optimization and approximation algorithms and on related complexity issues.]

[OR&IE 626 Advanced Production and Inventory Planning

Spring. 3 credits. Not offered 1997–98; next offered 1998–99.

Introduction to a variety of production and inventory control planning problems; the development of mathematical models corresponding to these problems; a study of approaches for finding solutions.]

OR&IE 630 Mathematical Programming I

Fall. 4 credits. Prerequisites: advanced calculus and elementary linear algebra.

A rigorous treatment of the theory and computational techniques of linear programming and its extensions. Formulation, duality theory, simplex, and dual simplex methods. Sensitivity analysis. Network flow problems and algorithms. Theory of polyhedral convex sets, systems of linear equations and inequalities, Farkas' Lemma. Exploiting special structure in the simplex method, computational implementation. Decomposition Principle.

[OR&IE 631 Mathematical Programming II

Spring. 4 credits. Prerequisite: OR&IE 630. Not offered 1997–98; next offered 1998–99.

A continuation of OR&IE 630. Introduction to nonlinear programming, interior-point methods for linear programming, complexity theory, and integer programming. Some discussion of dynamic programming, and elementary polyhedral theory.]

[OR&IE 632 Nonlinear Programming

Fall. 3 credits. Prerequisite: OR&IE 630. Not offered 1997–98; next offered 1998–99.

Necessary and sufficient conditions for unconstrained and constrained optima. Duality theory. Computational methods for unconstrained (e.g., quasi-Newton) problems, linearly constrained (e.g., active set) problems, and nonlinearly constrained (e.g., successive quadratic programming) problems.]

OR&IE 633 Graph Theory and Network Flows

Spring. 3 credits. Prerequisite: permission of instructor.

Directed and undirected graphs. Bipartite graphs. Hamilton cycles and Euler tours. Connectedness, matching, and coloring. Flows in capacity-constrained networks. Maximum flow and minimum cost flow problems.

[OR&IE 634 Combinatorial Optimization

Fall. 3 credits. Prerequisite: permission of instructor. Not offered 1997–98; next offered 1998–99.

Topics in combinatorics, graphs, and networks, including matching, matroids, polyhedral combinatorics, and optimization algorithms. Topics change each semester. This course may be taken more than once for credit.]

OR&IE 635 Interior-Point Methods for Mathematical Programming

Spring. 3 credits. Prerequisites: MATH 411 and OR&IE 630, or permission of instructor.

Interior-point methods arising from Karmarkar's Algorithm. Application to linear and quadratic programming and the linear complementarity problem. Projective-scaling, affine-scaling, path-following, and potential-reduction methods.

OR&IE 636 Integer Programming

Fall. 3 credits. Prerequisite: OR&IE 630.

Discrete optimization. Linear programming in which the variables must assume integral values. Theory, algorithms, and applications. Cutting-plane and enumerative methods, with additional topics drawn from recent research in this area.

[OR&IE 639 Polyhedral Convexity

Spring. 3 credits. Prerequisite: basic knowledge of linear algebra. Not offered 1997–98; next offered 1998–99.

A comprehensive introduction to the geometry and combinatorics of polyhedral convex sets. Linear inequalities, supporting and separating hyperplanes. Polarity. Convex hulls, facets, and vertices. Face lattices. Convex cones and polytopes. Minkowski sums. Gale transforms. Simplicial and polyhedral subdivision. Applications to linear programming, combinatorial optimization, and computational geometry.]

OR&IE 650 Applied Stochastic Processes

Fall. 4 credits. Prerequisite: a one-semester calculus-based probability course.

An introduction to stochastic processes that presents the basic theory together with a variety of applications. Topics include Markov processes, renewal theory, random walks, branching processes, Brownian motion, stationary processes, martingales, and point processes.

OR&IE 651 Probability

Spring. 4 credits. Prerequisite: real analysis at the level of Math 413 and a previous one-semester course in calculus-based probability.

Sample spaces, events, sigma fields, probability measures, set induction, independence, random variables, expectation, review of important distributions and transformation techniques, convergence concepts, laws of large numbers and asymptotic normality, conditioning.

[OR&IE 662 Advanced Stochastic Processes

Fall. 3 credits. Prerequisite: OR&IE 651 or equivalent. Not offered 1997–98; next offered 1998–99.

Brownian motion, martingales, Markov processes, and topics selected from: diffusions, stationary processes, point processes, weak convergence for stochastic processes and applications to diffusion approximations, Lévy processes, regenerative phenomena, random walks, and stochastic integrals.]

[OR&IE 663 Time-Series Analysis
Fall. 3 credits. Prerequisite: OR&IE 650 or equivalent. Not offered 1997–98; next offered 1998–99.
Representations of stationary time series. The ARIMA models. Spectral analysis. Long-range dependence. Problems of estimation. Multivariate time series.]

OR&IE 670 Statistical Principles
Fall. 4 credits. Co-requisite: OR&IE 650 or equivalent.
Review of distribution theory of special interest in statistics: normal, chi-square, binomial, Poisson, t, and F; introduction to statistical decision theory; sufficient statistics; theory of minimum variance unbiased point estimation; maximum likelihood and Bayes estimation; basic principles of hypothesis testing, including Neyman-Pearson Lemma and likelihood ratio principle; confidence interval construction; introduction to linear models.

OR&IE 671 Intermediate Applied Statistics
Spring. 3 credits. Prerequisite: OR&IE 670 or equivalent.
Statistical inference based on the general linear model; least-squares estimators and their optimality properties; likelihood ratio tests and corresponding confidence regions; simultaneous inference. Applications in regression analysis and ANOVA models. Variance components and mixed models. Use of the computer as a tool for statistics is stressed.

OR&IE 672 Selected Topics in Environmental Statistics (also BTRY 672)
Fall, spring. 2 credits. Prerequisite: ENGRD 270 or equivalent.
For description, see BTRY 672.

[OR&IE 676 Statistical Analysis of Life Data
Fall. 3 credits. Prerequisite: OR&IE 671 or equivalent. Not offered 1997–98; next offered 1998–99.
Analysis of data from reliability, fatigue, and life-testing studies in engineering; biomedical applications. Survival distributions, hazard rate, censoring. Life tables. Estimation and hypothesis testing. Standards. Goodness of fit, hazard plotting. Covariance analysis, accelerated life testing. Multiple decrement models, competing risks. Sample-size determination. Adaptive sampling.]

[OR&IE 678 Asymptotic Methods in Statistics
Fall. 3 credits. Prerequisite: OR&IE 670 or MATH 574. Not offered 1997–98; next offered 1998–99.
Topics chosen from: large-sample behavior of MLEs and other estimates; chi-square, likelihood ration, and related tests; Pitman and Bahadur efficiency; LAN families and LAM estimates; statistical applications of Edgeworth expansions; adaptive estimation and semiparametric inference, rank statistics, EDF and sample quantiles, nonparametric estimation, and smoothing.]

[OR&IE 680 Simulation
Spring. 4 credits. Prerequisite: permission of instructor. Not offered 1997–98; next offered 1998–99.
An advanced version of OR&IE 580, intended for Ph.D.-level students.]

OR&IE 728–729 Selected Topics in Applied Operations Research
Fall, spring. Credit to be arranged.
Current research topics dealing with applications of operations research.

OR&IE 738–739 Selected Topics in Mathematical Programming
Fall, spring. Credit to be arranged.
Current research topics in mathematical programming.

OR&IE 768–769 Selected Topics in Applied Probability
Fall, spring. Credit to be arranged.
Topics are chosen from current literature and research areas of the staff.

OR&IE 778–779 Selected Topics in Applied Statistics
Fall, spring. Credits to be arranged.
Topics chosen from current literature and research of the staff.

OR&IE 790 Special Investigations
Fall, spring. Credit to be arranged.
For individuals or small groups. Study of special topics or problems.

OR&IE 799 Thesis Research
Fall, spring. Credit to be arranged.
For individuals doing thesis research for master's or doctoral degrees.

OR&IE 891 Operations Research Graduate Colloquium
Fall, spring. 1 credit.
A weekly 1-1/2 hour meeting devoted to presentations by distinguished visitors, by faculty members, and by advanced graduate students on topics of current research in the field of operations research.

OR&IE 893–894 Applied OR&IE Colloquium (also M&AE 594)
893, fall; 894, spring. 1 credit each term.
A weekly meeting for Master of Engineering students. Discussion of various topics on manufacturing with faculty members and outside speakers.

THEORETICAL AND APPLIED MECHANICS

Basics in Engineering Mathematics and Mechanics

T&AM 118 Design Integration: A Portable CD Player (also MS&E and ENGRI 118)
Spring. 3 credits.
For description, see ENGRI 118.

T&AM 202 Mechanics of Solids (also ENGRD 202)
Fall, spring. 3 credits Prerequisite: PHYS 112, coregistration in MATH 293 or permission of instructor.
For description, see ENGRD 202.

T&AM 203 Dynamics (also ENGRD 203)
Fall, spring. 3 credits. Prerequisite: T&AM 202, coregistration in MATH 294, or permission of instructor.
For description, see ENGRD 203.

Engineering Mathematics

T&AM 191 Calculus for Engineers (also MATH 193)
Fall. 4 credits. Prerequisite: 3 years of high school mathematics, including trigonometry.
For description, see MATH 191.

T&AM 192 Calculus for Engineers (also MATH 192)
Fall, spring, or summer. 4 credits. Prerequisite: MATH/T&AM 191/193.
For description, see MATH 192.

T&AM 193 Calculus for Engineers (also MATH 193)
Fall. 4 credits. Prerequisite: 3 years of high school mathematics, including trigonometry.
For description, see MATH 193.

T&AM 293 Engineering Mathematics (also MATH 293)
Fall, spring. 4 credits. Prerequisite: MATH/T&AM 192 plus a knowledge of computer programming equivalent to that taught in COM S 100.
For description, see MATH 293.

T&AM 294 Engineering Mathematics (also MATH 294)
Fall, spring. 4 credits. Prerequisite: MATH/T&AM 293.
For description, see MATH 294.

T&AM 310 Advanced Engineering Analysis I
Fall, spring. 3 credits. Prerequisite: MATH/T&AM 294 or equivalent.
Initial value, boundary value, and eigenvalue problems in linear ordinary differential equations. Special functions, linear partial differential equations. Introduction to probability and statistics. Use of computers to solve problems.

T&AM 311 Advanced Engineering Analysis II
Spring. 3 credits. Prerequisite: MATH/T&AM 294 or equivalent (T&AM 311 can be taken without T&AM 310).
Introduction to complex variable theory. Cauchy's Integral theorem, Laurent series, Classification of singularities, Method of Residues. Applications include conformal mapping (Laplace equation), Laplace transform, Fourier transform, Fourier series, Transfer function, Solution and stability of Linear Systems. Examples are drawn from fluid mechanics, heat transfer, electromagnetics, and elasticity.

T&AM 610 Methods of Applied Mathematics I
Fall. 3 credits. Intended for beginning graduate students in engineering and science. An intensive course, requiring more time than is normally available to undergraduates (see T&AM 310–311) but open to exceptional undergraduates with permission of instructor.
Emphasis is on applications. Linear algebra, calculus of several variables, vector analysis, series, ordinary differential equations, complex variables.

T&AM 611 Methods of Applied Mathematics II
Spring. 3 credits. Prerequisite: T&AM 610 or equivalent.
Emphasis on applications. Partial differential equations, transform techniques, tensor analysis, calculus of variations.

T&AM 612 Methods of Applied Mathematics III

Fall. 3 credits. Prerequisite: T&AM 610 and 611 or equivalent.

Integral transform, methods, Wiener-Hopf technique, solutions of integral equations and partial differential equations. Problems drawn from electromagnetics, elasticity, fluid mechanics, heat transfer, and acoustics.

T&AM 613 Methods of Applied Mathematics IV

Spring. 3 credits. Prerequisite: T&AM 610 and 611 or equivalent.

Topics include asymptotic behavior of solutions of linear and nonlinear ODE (e.g., the WKB boundry layer and multiple-scale methods), asymptotic expansion of integrals (method of steepest descent, stationary phase and Laplace methods). Regular and singular perturbation methods for PDE (e.g., method of composite expansions). Other topics (depending on instructor) may include normal forms, center manifolds, Liapunov-Schmidt reductors, Stokes phenomenon. The course may also include computer exercises at the option of the instructor.

Continuum Mechanics

T&AM 455 Introduction to Composite Materials (also M&AE 455 and MS&E 455)

Spring. 4 credits.

Introduction to composite materials; varieties and properties of fiber reinforcements and matrix materials; micromechanics of stiffness and stress transfer in discontinuous fiber/matrix arrays; orthotropic elasticity as applied to parallel fibers in a matrix and lamina; theory of stiffness (tension, bending, torsion) and failure of laminates and composite plates including computer software for design; manufacturing methods and applications for composites. There is a group component design and manufacturing paper required, and a group laboratory on laminated component fabrication.

T&AM 591 Master of Engineering Design Project I

Fall. 3–6 credits.

M. Eng. (Mechanics) project related to the mechanics of advanced composites and structures.

T&AM 592 Master of Engineering Design Project II

Spring. 5–15 credits.

M. Eng. (Mechanics) project related to the mechanics of advanced composites and structures.

T&AM 655 Composite Materials (also M&AE 655 and MS&E 655)

Spring. 4 credits.

Taught jointly with T&AM 455 using same lecture material, but also includes more advanced material and homeworks through additional lectures. Additional material includes: shear-lag models of stress transfer around arrays of fiber breaks including viscoelastic effects, statistical theories of composite strength and failure; stress distributions around holes and cuts in composite laminates; compressive strength of composites. Laboratory on effects of holes and notches in composites.

T&AM 663 Solid Mechanics I

Fall. 4 credits.

Rigorous introduction to solid mechanics emphasizing linear elasticity: tensors; deformations, rotations and strains; balance principles; stress; small-strain theory; linear elasticity, anisotropic and isotropic; basic theorems of elastostatics; boundary-value problems, e.g. plates, St. Venant's solutions.

T&AM 664 Solid Mechanics II

Spring. 4 credits. Prerequisites: MATH 610 and T&AM 663, or equivalent.

Preparation for advanced courses in solid mechanics. Singular solutions in linear elasticity; plane stress, plane strain, anti-plane shear, Airy stress functions; linear viscoelasticity; cracks and dislocations; classical plasticity; thermoelasticity; three-dimensional elasticity.

T&AM 666 Finite Element Analysis for Mechanical, Structural and Aerospace Applications (also CEE 772 and M&AE 680)

Spring. 3 credits. Prerequisite: T&AM 663.

For description, see M&AE 680.

T&AM 751 Continuum Mechanics and Thermodynamics

Fall. 3 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 or equivalents.

Kinematics; conservation laws; the entropy inequality; constitutive relations: frame indifference, material symmetry; finite elasticity, rate-dependent materials, and materials with internal state variables.

[T&AM 752 Nonlinear Elasticity

Spring. 3 credits. Prerequisites: T&AM 610, 611, and 751 or equivalents. Offered alternate years. Not offered 1997–98.

Review of governing equations. Linearization and stability; constitutive inequalities; exact solution of special problems; nonlinear string and rod theories; phase transformations and crystal defects.]

T&AM 753 Fracture

Fall. 3 credits. Prerequisites: T&AM 610 or 611; and 663 and 664 or equivalents. Offered alternate years.

Fundamentals of linear elastic fracture mechanics: K, small-scale yielding, solutions of elastic crack problems, energy concepts, J-integral. Nonlinear, rate-independent, small-deformation, fracture mechanics: plastic fracture, J-integral, small-scale yielding, fields for stationary and growing cracks. Failure mechanisms of polymers, ceramics, composites, and metals: void growth, load transfer between fibers, crazing. Fracture testing. Fatigue fracture. Computation of stress intensity factors. Plate theory and fracture.

T&AM 757 Inelasticity

Spring. 3 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 or equivalents. Offered alternate years.

Plasticity: dislocation slip systems; early experimental observations; general principles; limit analysis; solution of boundary-value problems, plastic waves, one- and three-dimensional. Visco-elasticity: general principles, solution of boundary-value problems.

[T&AM 759 Boundary Element Methods

Fall. 4 credits. Prerequisites: T&AM 610 and 611; and 633 and 644 or equivalents. Offered alternate years. Not offered 1997–98.

Introduction to boundary element methods. Solutions for potential theory, linear elasticity, diffusion, material and/or geometric nonlinearities. Modern developments: hypersingular integrals, the boundary contour methods, sensitivity analysis.]

[T&AM 768 Elastic Waves

Fall. 3 credits. Prerequisites: T&AM 610 or 611; and 633 and 574 or equivalents. Offered alternate years. Not offered 1997–98.

An advanced course on dynamic stress analysis and wave propagation in elastic solids. Theory of elastodynamics; waves in isotropic and anisotropic medium; reflection and refraction; surface waves and waves in layered media; transient waves and methods of Lamb-Cagiard-Pakeris; thick plate theories; vibrations of spheres; scattering of waves and dynamic stress concentrations.]

Dynamics and Space Mechanics

T&AM 570 Intermediate Dynamics

Fall. 3 credits.

Newtonian mechanics; motion in rotating coordinate systems. Introduction to analytical mechanics; virtual work, Langrangian mechanics. Hamilton's principle. Small vibration and stability theory. Newtonian-Eulerian mechanics of rigid bodies. Gyroscopes.

[T&AM 574 Vibrations and Waves in Elastic Systems (also M&AE 577)

Spring. 4 credits. Prerequisites: T&AM 570 and 610. 3 lectures, one lab. Not offered 1997–98.

Oscillations and one- and two-degree-of-freedom vibrating systems. General properties of vibrating systems. Modal analysis. Vibration of continuous systems. Elementary nonlinear systems and chaos. Characterization of vibrating systems. Measurements and applications. Two vibrations laboratory experiments.]

T&AM 578 Nonlinear Dynamics and Chaos

Spring. 3 credits. Prerequisite: Mathematics/T&AM 293 or equivalent.

Introduction to nonlinear dynamics, with applications to physics, engineering, biology and chemistry. Emphasizes analytical methods, concrete examples, and geometric thinking. Topics: One-dimensional systems. Bifurcations. Phase plane. Nonlinear oscillators. Lorenz equations, chaos, strange attractors, fractals, iterated mappings, period doubling, renormalization.

[T&AM 671 Advanced Dynamics

Spring. 3 credits. Prerequisite: T&AM 570 or equivalent. Offered alternate years. Not offered 1997–98.

Review of Lagrangian mechanics, Kane's equations; Hamilton's principle, the principle of least action, and related topics from the calculus of variations; Hamilton's canonical equations; approximate methods for two-degrees-of-freedom systems (Lie transforms); canonical transformations and Hamilton-Jacobi theory; KAM theory; Melnikov's method.]

[T&AM 672 Celestial Mechanics (also ASTRO 579)

Spring. 3 credits. Offered alternate years. Not offered 1997–98.

Description of orbits; 2-body, 3-body, and n-body problems; Hill curves, libration points and their stability; capture problems. Osculating orbital elements, perturbation equations; effects of gravitational potentials, atmospheric drag, and solar radiation forces on satellite orbits; secular perturbations, resonances, mechanics of planetary rings.]

[T&AM 673 Mechanics of the Solar System (also ASTRO 571)

Spring. 3 credits. Prerequisite: an advanced undergraduate course in dynamics. Offered alternate years. Not offered 1997–98.

Gravitational potentials, planetary gravity fields. Free and forced rotations. Chandler wobble, polar wander, damping of nutation. Equilibrium tidal theory, tidal heating. Orbital evolution of natural satellites, resonances, spin-orbit coupling, Cassini states. Long-term variations in planetary orbits. Dust dynamics. Dynamics of ring systems. Physics of interiors, seismic waves, free oscillations. Illustrative examples are drawn from contemporary research.]

T&AM 675 Nonlinear Vibrations

Fall. 3 credits. Prerequisite: T&AM 578 or equivalent. Offered alternate years.

Quantitative analysis of weakly nonlinear systems in free and forced vibrations, perturbation methods, averaging method. Applications to problems in mechanics, physics, and biology. Additional topics may include Hopf bifurcation, Invariant manifolds, coupled oscillators, vibrations in continuous media, normal forms, and exploitation of symmetry.

[T&AM 776 Applied Dynamical Systems

Not offered 1997–98.

For description, see MATH 617.]

Special Courses, Projects, and Thesis Research

T&AM 491–492 Project in Engineering Science

491, fall; 492, spring. 1–4 credits, as arranged.

Projects for undergraduates under the guidance of a faculty member.

T&AM 796–800 Topics in Theoretical and Applied Mechanics

Fall, spring. 1–3 credits, as arranged.

Special lectures or seminars on subjects of current interest. Topics are announced when the course is offered.

T&AM 890 Master's Degree Research in Theoretical and Applied Mechanics

Fall, spring. 1–15 credits, as arranged. S-U grades optional.

Thesis or independent research at the M.S. level on a subject of theoretical and applied mechanics. Research is under the guidance of a faculty member.

T&AM 990 Doctoral Research in Theoretical and Applied Mechanics

Fall, spring. 1–15 credits, as arranged. S-U grades optional.

Thesis or independent research at the Ph.D. level on a subject of theoretical and applied mechanics. Research is under the guidance of a faculty member.

FACULTY ROSTER

Abel, John F., Ph.D., U. of California at Berkeley. Prof., Civil and Environmental Engineering

Ahner, Beth A., Ph.D., Massachusetts Institute of Technology. Asst. Prof., Agricultural and Biological Engineering

Albright, Louis D., Ph.D., Cornell U. Prof., Agricultural and Biological Engineering

Allmendinger, Richard, Ph.D., Stanford U. Prof., Geological Sciences

Aneshansley, Daniel J., Ph.D., Cornell U. Assoc. Prof., Agricultural and Biological Engineering

Anton, A. Brad, Ph.D., California Inst. of Technology. Assoc. Prof., Chemical Engineering

Ast, Dieter G., Ph.D., Cornell U. Prof., Materials Science and Engineering

Attoh, K., Ph.D., Northwestern U., Assoc. Prof., Geological Sciences

Avedisian, C. Thomas, Ph.D., Princeton U. Prof., Mechanical and Aerospace Engineering

Ballantyne, Joseph M., Ph.D., Massachusetts Inst. of Technology. Prof., Electrical Engineering

Barazangi, Muawia, Ph.D., Columbia U. Senior Scientist, Geological Sciences

Bartel, Donald L., Ph.D., U. of Iowa. Prof., Mechanical and Aerospace Engineering

Bartsch, James A., Ph.D., Purdue U. Assoc. Prof., Agricultural and Biological Engineering

Bassett, William A., Ph.D., Columbia U. Prof., Geological Sciences

Batterman, Boris W., Ph.D., Massachusetts Inst. of Technology. Walter S. Carpenter, Jr. Professorship in Engineering, Applied and Engineering Physics

Berger, Toby, Ph.D., Harvard U. J. Preston Levis Professor of Engineering, Electrical Engineering

Billera, Louis J., Ph.D., City U. of New York. Prof., Operations Research and Industrial Engineering

Bird, John M., Ph.D., Rensselaer Polytechnic Inst. Prof., Geological Sciences

Birman, Kenneth P., Ph.D., U. of California at Berkeley. Prof., Computer Science

Bisogni, James J., Ph.D., Cornell U. Assoc. Prof., Civil and Environmental Engineering

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Bland, Robert G., Ph.D., Cornell U. Prof., Operations Research and Industrial Engineering

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Cisne, John L., Ph.D., U. of Chicago. Prof., Geological Sciences

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Clark, David D., Ph.D., U. of California at Berkeley. Prof., Engineering

Cohen, Claude, Ph.D., Princeton U. Prof., Chemical Engineering

Coleman, Thomas F., Ph.D., U. of Waterloo. Prof., Computer Science

Compton, Richard C., Ph.D., California Inst. of Technology. Assoc. Prof., Electrical Engineering

Constable, Robert L., Ph.D., U. of Wisconsin. Prof., Computer Science

Cooke, J. Robert, Ph.D., North Carolina State U. Prof., Agricultural and Biological Engineering

Cool, Terrill A., Ph.D., California Inst. of Technology. Prof., Applied and Engineering Physics

Craighead, Harold G., Ph.D., Cornell U. Prof., Applied and Engineering Physics, and Electrical Engineering

D'Andrea, Raffaello, Ph.D., California Inst. of Tech. Asst. Prof., Mechanical and Aerospace Engineering

Datta, Ashim K., Ph.D., U. of Florida. Assoc. Prof., Agricultural and Biological Engineering

Dawson, Paul R., Ph.D., Colorado State U. Prof., Mechanical and Aerospace Engineering

deBoer, P. Tobias, Ph.D., U. of Maryland. Prof., Mechanical and Aerospace Engineering

Deierlein, Gregory G., Ph.D., U. of Texas at Austin. Assoc. Prof., Civil and Environmental Engineering

Delchamps, David F., Ph.D., Harvard U. Assoc. Prof., Electrical Engineering

Derry, Louis, Ph.D., Harvard U. Asst. Prof., Geological Sciences

Dick, Richard I., Ph.D., U. of Illinois. Joseph P. Ripley Professor of Engineering, Civil and Environmental Engineering

Dieckmann, Rudiger, Ph.D., Technical U. of Clausthal. Prof., Materials Science and Engineering

Duncan, Michael, Ph.D., California Inst. of Technology. Assoc. Prof., Chemical Engineering

Eastman, Lester F., Ph.D., Cornell U. Given Foundation Professor of Engineering, Electrical Engineering

Engstrom, James R., Ph.D., California Inst. of Technology. Assoc. Prof., Chemical Engineering

Farley, Donald T., Ph.D., Cornell U. Prof., Electrical Engineering

Fine, Terrence L., Ph.D., Harvard U. Prof., Electrical Engineering

Fisher, Elizabeth M., Ph.D., U. of California at Berkeley. Asst. Prof., Mechanical and Aerospace Engineering

Fleischmann, Hans H., Ph.D., Technische Hoch., München (Germany). Prof., Applied and Engineering Physics
Gaeta, Alexander L., Ph.D., U. of Rochester. Asst. Prof., Applied and Engineering Physics
Gebremedhin, Kifle G., Ph.D., U. of Wisconsin. Prof., Agricultural and Biological Engineering
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Godfrey, Michael, Ph.D., U. of Toronto. Asst. Prof., Computer Science
Gossett, James M., Ph.D., Stanford U. Prof., Civil and Environmental Engineering
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Gries, David J., Ph.D., Technische Hoch., München (Germany). William L. Lewis Prof. of Engineering, Computer Science
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Haas, Zygmunt J., Ph.D., Stanford U. Assoc. Prof., Electrical Engineering
Haith, Douglas A., Ph.D., Cornell U. Prof., Agricultural and Biological Engineering
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Hammer, David A., Ph.D., Cornell U. J. Carlton Ward Sr. Prof. of Electrical Engineering
Harriott, Peter, Sc.D., Massachusetts Inst. of Technology. Fred H. Rhodes Professor of Chemical Engineering
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Pitt, Ronald E., Ph.D., Cornell U. Prof., Agricultural and Biological Engineering
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Pope, Stephen B., Ph.D., Imperial College of Science and Technology (England). Prof., Mechanical and Aerospace Engineering
Pottle, Christopher, Ph.D., U. of Illinois. Prof., Electrical Engineering
Psiaki, Mark L., M.A., Princeton U. Assoc. Prof., Mechanical and Aerospace Engineering
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Rhodes, Frank H. T., Ph.D., U. of Birmingham (England). Prof., Geological Sciences
Rodriguez, Ferdinand, Ph.D., Cornell U. Prof., Chemical Engineering
Rosakis, Phoebus, Ph.D., California Inst. of Technology. Assoc. Prof., Theoretical and Applied Mechanics
Roundy, Robin, Ph.D., Stanford U. Assoc. Prof., Operations Research and Industrial Engineering
Rubinfeld, Ronitt, Ph.D., U. of California at Berkely. Asst. Prof., Computer Science
Ruina, Andy L., Ph.D., Brown U. Assoc. Prof., Theoretical and Applied Mechanics
Ruoff, Arthur L., Ph.D., U. of Utah. Class of 1912 Professor, Materials Science and Engineering
Ruppert, David, Ph.D., Michigan State U. Prof., Operations Research and Industrial Engineering
Sachse, Wolfgang H., Ph.D., Johns Hopkins U. Meinig Family Prof. of Engineering, Theoretical and Applied Mechanics
Saltzman, W. Mark, Ph.D., Massachusetts Inst. of Technology/Harvard U. Prof., Chemical Engineering
Samorodnitsky, Gennady, D.S., Technion-Israel Inst. of Technology. Assoc. Prof., Operations Research and Industrial Engineering
Sansalone, Mary J., Ph.D., Cornell U. Assoc. Prof., Civil and Environmental Engineering
Sass, Stephen L., Ph.D., Northwestern U. Prof., Materials Science and Engineering
Schneider, Fred B., Ph.D., SUNY at Stony Brook. Prof., Computer Science
Schruben, Lee W., Ph.D., Yale U. Prof., Operations Research and Industrial Engineering
Schuler, Richard E., Ph.D., Brown U. Prof., Civil and Environmental Engineering/ Economics
Scott, Norman R., Ph.D., Cornell U. Prof., Agricultural and Biological Engineering
Seshadri, Praveen, Ph.D., U. of Wisconsin. Asst. Prof., Computer Science
Seyler, Charles E., Jr., Ph.D., U. of Iowa. Prof., Electrical Engineering
Shacham-Diamand, Yosef Y., D.Sc., Israel Institute of Technology. Asst. Prof., Electrical Engineering
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