COLLEGE OF ENGINEERING

ADMINISTRATION

William B. Streett, dean

K. Bingham Cady, associate dean for college affairs

S. Leigh Phoenix, associate dean for research and graduate studies

Gerald Rehkugler, associate dean for undergraduate affairs

Mary Thompson, assistant dean for minority programs

Mark K. Spiro, director of administration

Richard Hale, director of admissions

Edwin Gordon, director of advising

Michele Fish, assistant director of advising

Richard K. Mosher, registrar

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 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.

Computing equipment, for example, is available through centers administered by the university and by the College of Engineering, as well as in laboratories run by schools, departments, or programs. The university facilities include personal computers for student use, terminals connected to the mainframe, computer-graphics equipment, and a supercomputer. The College of Engineering operates, in addition to several computing centers for student use, the Computer-Aided Design Instructional Facility, which provides advanced computer-graphics equipment used in course work throughout the college.

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 Environmental Research. A sponsor of interdisciplinary programs that are currently in the areas of environmental law and policy, ecosystem research, remote sensing, water resources, the global environment, biological resources, waste management, and solid-waste combustion.

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 national supercomputer facility used for advanced research in engineering and the physical and biological sciences.

Cornell High Energy Synchrotron Source. A high-energy synchrotron radiation laboratory operated in conjunction with the university's high-energy storage ring.

Cornell Manufacturing Engineering and Productivity Program. A joint venture of Cornell, industrial organizations, and the federal government to encourage the development and implementation of modern manufacturing systems.

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

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 equipment.

Mathematical Sciences Institute. An interdisciplinary program in applications of mathematics funded by the U.S. Army.

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

National Earthquake Engineering Research Center. A facility recently established by the National Science Foundation at a group of universities in New York State.

National Nanofabrication Facility. A center that provides equipment and services for research in the science, engineering, and technology of structures (including electronic components) with dimensions as small as the nanometer range.

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.

SRC Center for the 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.

Statistics Center. Coordinates a university-wide program in statistics and probability.

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

Programs sponsored by College of Engineering units include several for industrial affiliates. These are in the areas of injection molding, computer science, materials science, geologic study of the continents, and nanometer 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 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 Common Curriculum Governing Board (CCGB) through the associate dean for undergraduate programs and the Office of Advising. Subsequently most students enter *field* programs, which are described separately for each academic area. 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 within one of the field programs or through the College Program. Information about these options is available in the Office of Advising, 167 Olin Hall.

*Agricultural 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 engineering students generally enroll in the College of Agriculture and Life Sciences for the first, second, and fourth years, and jointly in that college and the College of Engineering for the third year.

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. The Common Curriculum is composed of courses in eight categories.

Course Category	*Credits*
1) Mathematics	16
2) Physics	12
3) Chemistry	4
4) Freshman writing seminar	6
5) Computer programming	4
6) Engineering distribution (4 courses)	12
7) Humanities and social sciences (6 courses)	18
8) Electives:	
Approved electives	9
Free electives	6
Technical electives	6

One approved course in computing applications must also be taken; this course may simultaneously satisfy some other requirement.

Credits for courses in the field program vary between 36 and 48, depending on which program is chosen. Because of this variation the credits needed for graduation range between 129 and 141. Two terms of physical education must be taken in the freshman year to satisfy a university requirement.

Mathematics

The normal program in mathematics includes Mathematics 191,192, 293, and 294. Students who have little or no acquaintance with calculus take Mathematics 191.

Physics

The normal program in physics includes Physics 112 or 116, 213 or 217, and 214 or 218. Students in the Field Programs in Civil Engineering or Operations Research and Industrial Engineering may substitute Chemistry 208 for Physics 214 upon approval of a petition to the field.

Chemistry

Chemistry 207 or 211 is required for all students. Chemistry 207 is normally taken in the first freshman semester; 211 may be taken either in the fall or spring of the freshman year.

Chemistry 211 is a course designed for students who do not intend any further study in chemistry. Therefore students who intend to take more chemistry should register for Chemistry 207 in the fall of their freshman year.

In general, students in the following departments and schools should take Chemistry 211: electrical engineering, operations research and industrial engineering, computer science, mechanical and aerospace engineering, applied and engineering physics (applied and engineering physics students should discuss this option with the field consultant), and civil engineering (not students in environmental engineering). Students in environmental engineering, materials science and engineering, geology and chemical engineering must take Chemistry 207 in the fall of their freshman year.

All students considering a health-related career, for example in medicine, should take Chemistry 207 in their first term.

Freshman Writing Seminars

Each semester of their freshman year, students choose a freshman writing seminar from among more than seventy courses offered by over twenty 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.

Computing

In either the first or second term of their freshman year, students take Engr 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 475, CS 212, Engr 211, Engr 222, Engr 241, Engr 264, EE 423, M&AE 389, M&AE 489, M&AE 575, and M&AE 670. The recommended choice for students intending to enter the Field Program in Engineering Physics is Engr 264; in Chemical Engineering, Engr 222 or 241; in Computer Science, Engr 211 or CS 212; in Electrical Engineering, Engr 211; in Civil Engineering, Engr 241; in Mechanical Engineering, M&AE 389, M&AE 489, M&AE 575, or M&AE 670; and in Operations Research and Engineering, Engr 211.

Engineering Distribution

Four engineering distribution courses (12 credits) are required. These courses must be selected from four of the eight areas listed below. A student may use only one of the possible substitutions described.

1) *Scientific computing*
   Engr 211, Computers and Programming
   Engr 222, Introduction to Scientific Computing
   Engr 241, Engineering Computation

Students in the Field Program in Computer Science may substitute CS 212 for Engr 211 (also CS 211).

2) *Materials science*
   Engr 261, Introduction to Mechanical Properties of Materials
   Engr 262, Introduction to Electrical Properties of Materials
3) *Mechanics*
   Engr 202, Mechanics of Solids
   Engr 203, Dynamics

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

4) *Probability and statistics*
   Engr 260, Introduction to Engineering Probability
   Engr 270, Basic Engineering Probability and Statistics

Students in the Field Program in Electrical Engineering may substitute EE 310 for Engr 260. Students in the Field Program in Engineering Physics may substitute EE 310 or Mathematics 471 for Engr 260. Students in the Field Programs in Civil Engineering and Agricultural Engineering may substitute CEE 304 for Engr 270.

5) *Electrical sciences*
   Engr 210, Introduction to Electrical Systems
   Engr 264, Computerized-Instrumentation Design

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

Students in the Field Program in Electrical Engineering may substitute EE 480 for Engr 221.

7) *Earth and life sciences*
   Engr 201, Introduction to the Physics and Chemistry of the Earth

8) *Introduction to engineering*

Several courses are offered to introduce freshmen to the various fields of engineering. Some of these courses, which begin with Engr 110, may not be included in this announcement. A full listing will be available in the Course and Room Roster at the time of registration.

Humanities and Social Sciences

The six required courses in the humanities and social sciences (totaling at least 18 credits) must be chosen from approved courses in three categories: (a) humanities or history, (b) social sciences, and (c) expressive or language arts.

Restrictions:* At least three courses and a minimum of 9 credits must be chosen from category (a), and no more than 4 credits may be chosen from category (c). One-credit courses are acceptable only in category (c). Furthermore, in satisfying the humanities and social sciences requirement, the courses selected must provide both breadth and depth, and not be limited to a selection of unrelated introductory courses. This means inclusion of: at least two courses from the same field, one of which is the explicit prerequisite for the other; **or** two related courses in the same field, at least one of which is numbered 300 or above (e.g., one of the history department prerequisites—History 151, 152, 190 or 191—together with a 300-level history course.)

*These restrictions apply to those students matriculating in fall of 1989 or later. Others should refer to earlier editions of this catalog.

a) Humanities or History

This category includes all courses (except English 285) designated by the College of Arts and Sciences as humanities and history (see Distribution Requirement section, group 2b and group 3a; disregard the phrase "Any two") as well as the following:

College of Agriculture and Life Sciences: Education 472, 473

College of Architecture, Art, and Planning: any course in architectural history except freshman seminars

College of Arts and Sciences: Economics 315, 326; History of Art, all courses numbered 200 and above; Music, all courses listed as introductory (except 120), music theory, and music history; Theatre Arts, only history, literature, and theory courses (performance courses are not acceptable)

College of Engineering: Engineering 250, 292

School of Industrial and Labor Relations: 100, 101, 140, 304, 305, 381, 382, 384, 406, 430, 502

b) Social Sciences

This category includes all courses designated by the College of Arts and Sciences as social sciences (see Distribution Requirement section, group 2a; disregard the phrase "Any two") as well as the following:

College of Agriculture and Life Sciences: Agricultural Economics 150, 252, 332; Communication 116, 120, 314, 416; Education 271, 317, 378; Natural Resources 201, 407; Rural Sociology, all courses

College of Architecture, Art, and Planning: Architecture 342; City and Regional Planning 400, 404, 413, 414

College of Arts and Sciences: Economics, all courses except 105, 315, 317, 318, 319, 320, 326

College of Engineering: Engineering 321, 322, 360, 400

College of Human Ecology: Consumer Economics and Housing 110, 111, 148, 247, 310, 355, 356, 430; Design and Environmental Analysis 250; Human Development and Family Study, all courses except 242, 243; Human Service Studies, all courses

School of Industrial and Labor Relations: All courses except: courses listed under category a); all courses in Economic and Social Statistics; Personnel and Human Resource Management 266; Interdepartmental Course 452

c) Expressive or Language Arts

This category includes all courses defined by the College of Arts and Sciences as expressive arts (see Distribution Requirement, group 3b) as well as the following:

College of Agriculture and Life Sciences: Communication, all courses; Floriculture, any course in freehand drawing and scientific illustration

College of Architecture, Art, and Planning: Art, all courses

College of Arts and Sciences: all nonliterature language courses and all music and theater arts courses that emphasize performance, acting, producing, or directing

College of Human Ecology: Design and Environmental Analysis 101, 111, 115

College of Engineering: Engineering 301, 350

School of Industrial and Labor Relations: Interdepartmental Course 452

Electives

There are three kinds of electives: approved, free, and technical. Approved electives must be an appropriate part of an overall educational plan or objective.* This constraint allows flexibility for individual goals while maintaining a coordinated, nontrivial program. A free elective may be any course in the university,† although all course selections must be approved by the student's faculty adviser. Technical electives are generally taken in the junior and senior years. They are usually upper-level courses in engineering, mathematics, or the physical sciences, but they also may be courses in other areas as designated by the student's field program.

Approved electives can help develop the skills of a broadly educated engineer, so students should give serious thought to their educational objectives and not propose approved-elective courses haphazardly. Advisers generally accept as approved electives: one introduction to engineering course, engineering distribution courses, courses stressing oral or written communication, upper-level engineering courses, advanced courses in mathematics, and rigorous courses in the biological and physical sciences. Courses in business, economics, and language are often approved by advisers when they serve a student's educational and academic objectives. In other cases, the student's interests are better served by approved electives that expand the field program or other parts of the curriculum, including the humanities and social sciences requirement.

*No ROTC courses may be used as approved electives unless they are colisted by an academic department.

†Except supplementary courses and ROTC courses at the 100 and 200 level not colisted by an academic department. Up to 6 credits of ROTC courses at the 300 level or above may be used as free electives.

Additional ROTC courses not colisted by an academic department may not be used to meet graduation requirements.

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, approved electives, and free electives, students are urged to consider courses listed within the "Science, Technology, and Society" 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.

Office of Advising

From the time that students enter the college as freshmen until they become affiliated with a major field or the College Program, they are under the administration of the Office of Advising, which implements the academic policies of the Common Curriculum Governing Board. The office also offers general advising and counseling services, publishes a college newsletter, and provides support for all students in the college. The Office of Minority Programs provides additional specialized services.

To remain in good standing, students in the College of Engineering must affiliate with a field by the end of their sophomore year, but some fields permit (and encourage) affiliation at the *beginning* of the sophomore year. Transfer students from outside Cornell automatically affiliate with a field of study on matriculation.

Engineering courses taken at the freshman and sophomore levels are listed under "Engineering Common Courses." Additional engineering courses of general interest are also listed in this section.

Following is a typical curriculum for freshmen who have not received advanced placement in mathematics. Many variations are possible, depending on the individual student's background, advanced placement credit, and career goals. Those receiving advanced placement for first term calculus may take Physics 112 in term one. Students with an interest in bioengineering may take biology in terms one and two as approved electives. Students preparing to study medicine should take one year of biology and Chemistry 208 in the first year.

Term 1	*Credits*
Math 191, Calculus for Engineers	4
Chem 207 or Chem 211,* General Chemistry	4
Engr 100, Introduction to Computer Programming	4
Introduction to Engineering, a humanities or social science course, or an approved elective	3
Freshman writing seminar	3

*Chem 211 may be postponed until term 2

Term 2	*Credits*
Math 192, Calculus for Engineers	4
Phys 112, Mechanics and Heat	4
Two electives	6 to 8
Freshman writing seminar	3

Field Program

The specific program for each field is described in the following pages. Students with a grade-point average of at least 2.0 who are making normal progress toward their degree must affiliate with a field program by the end of their sophomore year. Students who intend to enter the Field Program in Chemical Engineering should take Chemistry 208 and Chemistry 287–289 as approved electives in terms two and three, and Chemistry 288–290 as a field course in term four. Students intending to major in mechanical engineering must take Engr 203, and students in agricultural engineering must take Engr 221 as a field course in term three or four. Students intending to major in computer science must take CS280 as a field course in term three or four. Mechanical engineering students should also complete Engr 221 in their sophomore year. Students who intend to enter the Field Program in Electrical Engineering must earn grades of at least C in Math 293 and 294, at least C in Physics 213 and 214, and at least C+ in Engr 210.

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

Chemical Engineering: Engr 219

Civil Engineering: Engr 202

Computer Science: Engr 211 (or CS 212)

Electrical Engineering: Engr 210

Materials Science and Engineering: Engr 261

Mechanical Engineering: Engr 202

Operations Research and Engineering: Engr 260

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 early in the second 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. Generally, 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 42 credits in the major and minor subjects, including at least 21 credits in engineering courses, each program includes the normally required courses in humanities and social sciences and free electives.

Further information about the College Program may be obtained from the associate dean for undergraduate programs, 223 Carpenter Hall, or from a counselor in the Office of Advising, 167 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 a Bachelor of Arts degrees can be earned in about five years. Students registered in the College of Engineering or the College of Arts and Sciences may apply and, after acceptance of their application, begin the dual program in their second or third year. Those interested should contact the associate dean for undergraduate programs in 223 Carpenter Hall or see a counselor in the Office of Advising, 167 Olin Hall.

Double Major in Engineering

Another program that is attractive to many students is the double major. This 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 Office of Advising, 167 Olin Hall, and the individual field consultant offices.

Engineering Communications Program

The Engineering Communications Program offers instruction in written, oral, and visual presentation. Engineering Communications 350, a three-credit seminar course, is for students who desire intensive work in these areas. Examples from real-life engineering contexts are analyzed and specific assignments are often framed as professional case studies. Students learn to address audiences having different levels of technical expertise and to investigate the social and ethical implications of written and oral communication. A second course, Engineering 301, is offered only in conjunction with particular writing-intensive engineering courses. This one-credit class prepares students for the writing assignments in those courses.

In addition to classroom teaching, the Communications Program consults with faculty in engineering who wish to stress writing in their courses; maintains a writing-resource library; advises the staff of the *Cornell Engineer;* and arranges discussions of communications with students and alumni.

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 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 Cooperative Program office, 105 Hollister 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): Agricultural engineering

M.Eng.(Chemical): Chemical engineering

M.Eng.(Civil): Civil and environmental engineering

M.Eng.(Computer Science): Computer sciences

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.(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. The microelectronics manufacturing option is offered in the fields of electrical engineering, engineering physics, materials science and engineering, and chemical engineering. Both specializations are 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) 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. Beginning in the fall of 1990, selected courses that satisfy M.Eng. degree requirements in operations research and industrial engineering, computer science, and electrical engineering will be available in the Continuing Education Program. Application forms and further information are available from the Master of Engineering Office, 113 Hollister Hall, or from the M.Eng. chair, 248 Carpenter Hall.

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 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 other 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 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 special scholarship aid may be obtained from the Master of Engineering Office, 113 Hollister 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 may qualify for AP credit in one of two ways:

1) by receiving sufficiently high scores on advanced placement examinations given and scored by the College Entrance Examination Board (CEEB); or

2) by receiving sufficiently high scores on Cornell's departmental placement examinations, which are given during orientation week before fall-term classes begin. Advanced placement is granted only to first-term freshmen, and the placement examinations are scored before the students begin 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.

A 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 at the Office of Advising, 167 Olin Hall.

Transfer Credit

Entering freshmen and entering transfer 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.

College courses completed under the auspices of cooperative college and high school programs may be considered for advanced standing as follows. Credit for such courses is not granted unless students demonstrate academic proficiency by taking the appropriate CEEB or Cornell departmental placement examination, as described above.

After matriculation no more than 9 credits of transfer or Cornell extramural credit may be used to satisfy bachelor's degree requirements. Summer session courses at Cornell are the only exception to this rule.

A more detailed description of the college's regulations governing transfer credit may be found in the *Engineering Student Handbook*, available from the Office of Advising, 167 Olin Hall.

Academic Standing

The requirements for good standing in the college vary slightly among the different divisions. First-term freshmen must have a grade point average of 1.7 or higher with no failing, unsatisfactory, or *incomplete* grades and must be making adequate progress toward the four-year degree. Second-term freshman and sophomore requirements are the same, except that the grade-point average must be at least 2.0. Upperclass requirements for good standing and for satisfactory performance in courses that are prerequisite for field courses vary slightly for different fields of study, as specified in the following sections or the *Engineering Student Handbook*.

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 or higher with no failing, unsatisfactory, 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.

Standard of Performance for Mathematics

Every student must attain a grade of at least C– in Mathematics 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.

S-U Grades

The option of receiving a grade of "satisfactory" or "unsatisfactory" (S-U) in a particular course, rather than a grade on a graduated scale, may be selected only in the following circumstances. Students who want to take a course on an S-U basis must have completed at least one full semester of study at Cornell, and they may take only one course per semester on an S-U basis. Only courses in the humanities and social sciences, approved electives, and free electives may be taken as S-U courses. Students may preregister for the S-U option. To change a grading option, a properly completed and approved add/drop form must be filed with the registrar of the College of Engineering by the end of the first three weeks of the semester. After this deadline, the grading option *may not be changed under any circumstances* and no courses may be added with the S-U option selected.

The S-U policy does not apply to courses in physical education and other courses that are not taken to fulfill degree requirements. When a particular course is offered **only** on an S-U basis, a student may petition to take a second S-U course in the same term.

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 through the Extramural Division. Students who have been asked 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 9 credits earned through study in the Extramural Division 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. Such students must register for study in absentia and pay a fee. 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 Professor Richard Lance, 219 Kimball Hall, or with the staff of the Office of Advising, 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.

Students who have completed at least one semester at Cornell and wish to transfer into the College of Engineering can make application to the Office of Engineering Admissions—application forms are available in 167 Olin Hall. Students who would enter the college as second-semester sophomores or upperclassmen must be accepted by a field program as part of the admission process. Others may be accepted into the college without the requirement of field affiliation.

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

Leave of Absence and Withdrawal

Students may interrupt their studies for a period of time by taking a leave of absence. A formal petition must be filed, an exit interview conducted, and written approval granted. Leaves of absence for more than two years are not generally granted. Credit earned while on leave of absence is subject to the limitation placed on extramural and transfer credit.

Students who voluntarily *withdraw* from the engineering degree program sever all connection with the college, and if they subsequently want to return, they must make a formal application for readmission. Students who fail to register in the first three weeks of the semester, without having received a leave of absence or permission for study in absentia, may be classified, by action of the faculty, as having withdrawn.

ENGINEERING CAREER SERVICES

Individual advising and group seminars are available for students who desire assistance in career and job-search matters. Also, interviews are arranged between students and national company representatives who visit the campus to recruit employees. This service, which is available to both undergraduates and graduates, can be used to find permanent or summer employment. A résumé referral service is available to engineering alumni. Further information on all services is available from the Office of Engineering Placement, 201 Carpenter Hall.

AGRICULTURAL AND BIOLOGICAL ENGINEERING

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

Bachelor of Science Curriculum

The Field Program in Agricultural Engineering prepares students for engineering practice in biological and physical systems represented in agriculture and its supporting industries and agencies, environmental or resource protection agencies, the biotechnological industries, and the food industries. Engineering is applied to production, storage processing, distribution, and use of plant and animal products and biomass. Issues of environmental quality and safety and preservation of soil and water resources are studied. Emerging areas of study include engineering aspects of biotechnology. Biological, social, and agricultural sciences are integrated into the field program along with the engineering design and studies in the physical sciences. Areas of concentration include agricultural engineering, biological engineering, environmental systems, and food engineering.

This program is jointly administered by the College of Engineering and the College of Agriculture and Life Sciences. Students are enrolled in the College of Agriculture and Life Sciences in the first four semesters and jointly in the College of Engineering in the remaining semesters. Engineering college tuition is paid in the fifth and sixth semesters of study.

Graduates find employment not only in agricultural and food related industries but also in environmentally related firms and agencies. Professional education is also the choice of many of the graduates. Agricultural and biological engineers are employed throughout the entire spectrum of private industry, consulting firms, government agencies, utility companies, and educational institutions. The unique blend of engineering and the biological sciences in the education of the agricultural and biological engineer is often attractive to employers.

For further details see the department's undergraduate programs brochure, available at 106 Riley-Robb Hall.

The field program requirements are outlined below.

Basic Subjects	*Credits*
Math 191, 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	12
Introductory biological sciences	6 to 8
ABEN 151, computer programming and introduction to field	4 to 6
Engineering distribution (four courses, including Mechanics of Solids and Thermodynamics)	12
Humanities and social sciences (eight courses, including two in written expression, one in oral expression, and a minimum of 9 credits in humanities and/or history)	24
Advanced and Applied Subjects	
Engineering sciences in any field (must include fluid mechanics and dynamics), plus ABEN 250, 350, 351	
and a minimum of three agricultural and biological engineering courses (at least 9 credits) chosen from courses numbered 450 to 496 to total 33 credits	33
Biological or agricultural sciences (3 credits of upper level biological sciences required)	12
Free electives	6

Master of Engineering (Agricultural) Degree Program

The program for the M.Eng.(Agricultural) degree is intended primarily for those students who plan to enter engineering practice. The curriculum is planned as an extension of the Cornell 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. Six 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) degree may choose to concentrate in one of the subareas of agricultural engineering or take a broad program without specialization. The subareas are (a) agricultural engineering, (b) biological engineering, (c) environmental systems, and (d) food engineering. Engineering electives are chosen from among subject areas relevant to agricultural engineering, such as thermodynamics, process engineering, mechanical design and analysis, theoretical and applied mechanics, structural engineering, hydraulics, environmental engineering, soil engineering, waste management, and electronics.

APPLIED AND ENGINEERING PHYSICS

R. A. Buhrman, director; M. S. Isaacson, associate director; B. W. Batterman, J. D. Brock, K. B. Cady, D. D. Clark, T. A. Cool, H. G. Craighead, H. H. Fleischmann, V. O. Kostroun, J. A. Krumhansl, B. R. Kusse, R. L. Liboff, R. V. E. Lovelace, M. S. Nelkin, T. N. Rhodin, M. M. Salpeter, J. Silcox, R. N. Sudan, W. W. Webb, F. W. Wise, G. J. Wolga

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 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, geological analysis, laser and optical technology, microwave technology, nuclear technology, software engineering, and solid-state-device development. 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, computer science and engineering, electrical engineering, environmental science, fluid mechanics, geotechnology, laser optics, materials science and engineering, mechanical engineering, 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 A&EP 110, The Laser and Its Applications in Science, Technology, and Medicine (a freshman course); A&EP 264, Computerized-Instrumentation Design (a sophomore course); A&EP 363, Electronic Circuits (a junior course); Physics 410, Advanced Experimental Physics, and A&EP 436, Physical and Integrated Optics (senior courses).

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 Physics 112 or Physics 116 during their first semester (if their advanced placement credits permit) and to satisfy the computing applications requirement with an engineering distribution course such as A&EP 264. Engineering physics students need to take only three engineering distribution courses, since A&EP 333, which they take in their junior year, counts as a fourth member of this category.

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
Physics 410, Advanced Experimental Physics	4
A&EP 321, Mathematical Physics I; Mathematics 421; or T&AM 610 (applied mathematics)	4
A&EP 322, Mathematical Physics II; Mathematics 422; or T&AM 611 (applied mathematics)	4
Applications of quantum mechanics*	3 or 4
A third technical elective (in addition to the two required by the Common Curriculum)†	3

*Some courses that will satisfy this requirement are Physics 444, Nuclear and High-Energy Particle Physics; Physics 454, Introductory Solid-State Physics; A&EP 609, Low-Energy Nuclear Physics; EE 430, Lasers and Optical Electronics; and EE 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. With at least five electives in the junior and senior years, students are encouraged to develop areas of concentration in accordance with their individual career goals and interests. For those who look toward an industrial position after graduation, these electives should be chosen to widen the necessary background in a specific area of practical engineering. A different set of electives could 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. Various programs are described in a special brochure available from the School of Applied and Engineering Physics, Clark Hall. Students interested in such programs are advised to consult with a professor active in their area or with the associate director of the school, Professor Michael S. Isaacson.

Electives need not be all formal course work: Qualified students may undertake informal 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. While free electives may be selected (with the permission of the faculty adviser) from among almost all the courses offered at the university, the student is encouraged to select those that will provide further preparation in the area of technical interest. The minimum requirement is two courses or six credits.

The variety of course offerings provides a sizable flexibility in scheduling. In addition, if scheduling conflicts arise, the school may allow substitution of courses nearly equivalent to the listed required courses: Physics 325–326 is similar to A&EP 355–356; Physics 318 (offered in the spring) and T&AM 570 are similar to A&EP 333; Physics 443 (offered in the fall), is similar to A&EP 361; and advanced courses in fluid mechanics or elasticity are similar to A&EP 434.

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 term an overall grade point average of at least 2.3.

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, microstructure science and technology, device physics, or materials characterization. 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 microstructure science and technology. Core courses in this specialty include the microcharacterization of materials (A&EP 661) and the fabrication of microstructures and devices (A&EP 662). The design project may focus on such areas as semiconductor materials, device physics, microstructure technology, or optoelectronics.

Each individual program is planned by the student in consultation with the program chair. The object 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 (14 to 20 credits)
3) a required special-topics seminar course (4 credits)

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 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 electrical engineering, materials science, computer science, mechanical engineering, physical geology, or bioengineering).

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 R. V. E. Lovelace.

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, Sage 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

K. E. Gubbins, director; G. F. Scheele, associate director; A. B. Anton, P. Clancy, P. Clark, C. Cohen, T. M. Duncan, J. R. Engstrom, D. A. Hammer, P. Harriott, D. L. Koch, R. P. Merrill, W. L. Olbricht, A. Panagiotopoulos, F. Rodriguez, M. L. Shuler, P. H. Steen, W. B. Streett, J. A. Zollweg

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 Chemistry 208 as an approved elective during the freshman year. The program for the last three years, for students who have taken two engineering distribution courses during the first year, is as follows:

Term 3	*Credits*
Math 293, Engineering Mathematics	4
Phys 213, Electricity and Magnetism	4
Chem 287–289, Physical Chemistry (approved elective)	5
Chem E 219 (engineering distribution course)	3
Humanities or social sciences course	3
Term 4	
Math 294, Engineering Mathematics	4
Phys 214, Optics, Waves, and Particles	4
Chem 288–290, Physical Chemistry	5
Engineering distribution course	3
Humanities or social sciences course	3
Term 5	
Chem 357, Organic Chemistry†	3
Chem 251, Organic Chemistry Laboratory	2
Chem E 313, Chemical Engineering Thermodynamics	4
Chem E 323, Fluid Mechanics	3
Humanities or social sciences course	3
Term 6	
Chem 358, Organic Chemistry†	3
Chem E 101, Nonresident Lectures	0
Chem E 324, Heat and Mass Transfer	3
Chem E 332, Analysis of Separation Processes	4
Chem E 390, Reaction Kinetics and Reactor Design	3
Humanities or social sciences course	3
Term 7	
Chem E 432, Chemical Engineering Laboratory	4
Electives*	9
Humanities or social sciences course	3
Term 8	
Chem E 462, Chemical Process Design	4
Chem E 472, Process Control	3
Electives*	6
Humanities or social sciences course	3

*The electives in terms seven and eight comprise 6 credits of technical electives, 6 credits of free electives, and 3 credits of Chem E process or systems elective. Chem E process or systems electives include Chem E 566, Computer-aided Process Design; Chem E 640, Polymeric Materials; Chem E 643, Introduction to Bioprocess Engineering.

†Chemistry 253 plus an applied science elective may be substituted for Chem 357–358. Applied science electives include Biological Sciences 330 and 331, Principles of Biochemistry; Chem E 640, Polymeric Materials; Chem E 673, Adsorption and Catalysis; MS&E 331, Structural Characterization of Materials; MS&E 332, Electrical and Magnetic Properties of Materials; MS&E 441, Microprocessing of Materials; MS&E 442, Macroprocessing of Materials; Microbiology 290, General Microbiology Lectures; any A&EP course numbered 333 or above; any Chemistry course numbered 301 or above; any Physics course numbered 300 or above.

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 Chem E 711, 713, 731, 732, and 751
2) two courses in applied chemical engineering science chosen from Chem E 564, 566, 640, and 643
3) a minimum of 3 credits of a design project, Chem E 565

CIVIL AND ENVIRONMENTAL ENGINEERING

A. H. Meyburg, director; J. R. Stedinger, associate director; J. F. Abel, J. J. Bisogni, Jr., W. H. Brutsaert, G. G. Deierlein, R. I. Dick, P. Gergely, J. M. Gossett, M. D. Grigoriu, D. A. Haith, K. C. Hover, A. R. Ingraffea, G. H. Jirka, F. H. Kulhawy, J. A. Liggett, L. W. Lion, P. L-F. Liu, D. P. Loucks, W. R. Lynn, A. H. Nilson, T. D. O'Rourke, T. Peköz, W. R. Philipson, W. D. Philpot, M. J. Sansalone, R. E. Schuler, C. A. Shoemaker, 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. The civil engineering curriculum is designed to ensure adequate depth and breadth in each of the subdisciplines of civil engineering. For students who want to specialize in a particular subdiscipline, illustrative sets of courses are available in the school office (220 Hollister Hall). Students may emphasize structural engineering; civil engineering materials; geotechnical engineering; water quality and hazardous-waste engineering; environmental engineering; environmental management and planning; hydraulics, hydrology and fluid mechanics; and remote sensing.

Students planning to enter the Field Program in Civil Engineering are required to take Mechanics of Solids (Engr 202) during the sophomore year.* Prospective majors are strongly encouraged to obtain a "typical course schedule" from the school office.

For the Field Program in Civil Engineering the following courses are required in addition to those required for the Common Curriculum:†

Courses	*Credits*
Engr 202, Mechanics of Solids*	3
Engr 203, Dynamics	3
Engr 261, Introduction to Mechanical Properties of Materials*	3
Engr 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
Civil engineering distribution courses	12

Four civil engineering distribution courses must be selected from an approved list, and they must represent at least three of the different areas of civil engineering into which the list is categorized. The list is available at the school office, 220 Hollister Hall.

Civil engineering majors must also take at least two courses selected from a list of approved design courses (also available in 220 Hollister Hall), and must choose as one of their technical electives a 3-or-more-credit upper-level engineering course with design content. These requirements should not make it necessary to add any courses to the field program, although they do constrain the choice of civil engineering distribution courses or electives.

*These courses can also be used to satisfy the Common Curriculum requirements for engineering distribution courses.

†Chem 208 can be substituted for Phys 214.

††Engr 241 can be used to satisfy both the computer application requirement and an engineering distribution requirement of the Common Curriculum.

**Students in Civil Engineering may use CEE 304 as a substitute for Engr 270, applying it toward the engineering distribution requirement. If this is done, the technical elective requirement is increased by 3 credits. Alternatively, Engr 270 may be accepted (on petition) as a substitute for CEE 304 in the field program, but only if Engr 270 is taken before entry into the field.

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) Four courses: Management Practice (CEE 590), Engineering Management Methods (CEE 593), and the Management Project (CEE 591 and 592)
2) Two courses from a list of engineering management electives
3) Two elective courses in general management from outside the school, including accounting, finance, law and regulation, marketing, and organizational behavior
4) Two engineering and/or technical elective courses

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

G. Bilardi, K. Birman, B. Bloom, T. Coleman, R. L. Constable, B. Donald, D. Gries, J. Hartmanis, J. E. Hopcroft, D. Huttenlocher, D. Kozen, K. Marzullo, P. Panangaden, K. Pingali, G. Salton, F. B. Schneider, A. Segre, D. Subramanian, R. Teitelbaum, S. Toueg, C. Van Loan, S. Vavasis, V. Vazirani

Bachelor of Science Curriculum

The Field Program in Computer Science is intended for students who are interested in the computing process and in the fundamental structure of algorithms, data, and languages that underlie that process.

A student entering the Field Program in Computer Science must take CS 211 or 212 and CS 280 before beginning the upperclass sequence. Students who do not earn a grade of B– or better in both CS 211 or 212 and CS 280 are strongly advised against attempting the computer science field program. Students who have not maintained an average of at least 3.0 in the mathematics courses required by the Common Curriculum are also discouraged from entering the program. Apart from these requisites and those of the college, the courses required for the Field Program in Computer Science are:

Course Work	*Credits*
Systems sequence CS 314, Systems and Organization CS 410, Data Structures	8
Theory sequence CS 381 or 481, Theory of Computing CS 482, Analysis of Algorithms	8
Numerical Analysis CS 222, Scientific Computation, or CS 421, Numerical Solutions of Algebraic Equations	3–4
Electrical Engineering EE 230, Digital Systems*	4
Computer science electives	7–9

Two nonrequired computer science courses numbered 400 or above.† One must be a course or course-laboratory combination that includes a substantial programming project—for example, CS 412, 414–415, 417–418, 432–433, or 472.

Related electives	14–16

One mathematically oriented course plus three courses forming a coherent sequence in mathematics, operations research, electrical engineering, or another technical area.

*EE 230 also counts as an approved elective.

†Except CS 415, 418, 433, 600, 601, and seminar courses.

For more information, refer to the *Computer Science Undergraduate Handbook*, available from 303 Upson Hall.

The performance of students in the Field of Computer Science is reviewed each term. To remain in good standing with the department, they must have an overall term average of at least 2.3 with no courses failed and a term average for field program courses of at least 2.7 with no course grade less than C–, and they must be making satisfactory progress in the field.

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, application forms, and assistance in planning a curriculum, students should contact the computer science undergraduate coordinator in Upson Hall.

Master of Engineering (Computer Science) Degree Program

The one-year program leading to the degree of M.Eng.(Computer Science) admits fifteen to twenty students a year. 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.

In the curriculum the emphasis can be on programming languages and systems, on theory of algorithms and theory of computation, on numerical analysis, on artificial intelligence, or on information processing, which includes databases and information organization and retrieval. (Students who are interested in logical design or computer architecture will find it more appropriate to apply for admission to a graduate program in electrical engineering.) The required design project could be, for example, the design of a compiler for a large subset of a general-purpose programming language.

ELECTRICAL ENGINEERING

N. C. MacDonald, director; V. Anantharam, J. M. Ballantyne, T. Berger, A. W. Bojanczyk, G. M. Brown, R. R. Capranica, H.-D. Chiang, R. C. Compton, H. G. Craighead, D. F. Delchamps, L. F. Eastman, D. T. Farley, T. L. Fine, L. K. Grover, T. Hagfors, M. W. Hauser, C. Heegard, C. R. Johnson, Jr., M. C. Kelley, P. M. Kintner, R. Kline, J. P. Krusius, C. A. Lee, S.-Y. Lee, M. E. Leeser, R. L. Liboff, F. T.-C. Luk, P. R. McIsaac, J. A. Nation, N. F. Otani, T. W. Parks, C. R. Pollock, C. Pottle, A. P. Reeves, C. E. Seyler, Jr., J. R. Shealy, A. O. Steinhardt, R. N. Sudan, C. L. Tang, R. J. Thomas, J. S. Thorp, H. C. Torng, C. B. Wharton, E. D. Wolf, G. J. Wolga

Bachelor of Science Curriculum

Reflecting the large scope of this engineering discipline, the undergraduate Field Program in Electrical Engineering provides a broad foundation in a number of important and fundamental areas.

Areas of concentration 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.

Students planning to enter the Field Program in Electrical Engineering must take EE 210, Introduction to Electrical Systems, as an engineering distribution course. In addition, the field program requires twelve courses, as shown below. Many of these courses are taught only once a year, either spring or fall, as indicated in the course descriptions.

Course	*Credits*
EE 230, Introduction to Digital Systems	4
EE 301, Electrical Signals and Systems I	4
EE 303, Electromagnetic Waves and Fields I	4
EE 315, Electrical Laboratory	4
A choice of three courses from among: EE 302, Electrical Signals and Systems II EE 304, Electromagnetic Waves and Fields II EE 306, Fundamentals of Quantum and Solid State Electronics EE 308, Fundamentals of Computer Engineering EE 310, Probability and Random Signals	12
EE electives with laboratory (3 courses)	12
EE electives (2 courses)	6
Total	46*

*Credits in excess of 46 may be used to fill approved-, technical-, or free-elective requirements of the Common Curriculum.

EE electives may be selected from all courses taught in electrical engineering. At least one of the required EE electives with laboratory must be selected from a list including EE 316, 318, 425, 431, 435, 437, and 475. The other two may be selected from the above list or from among EE 423, 426, 432, 433, 436, 451, 452, 471, 476, 526, 534, 536, 539, and 572. (If EE 539 is taken for 6 credits, it counts as two courses. One course will count as an EE elective with laboratory, and the other may be used as an EE elective or to meet any other degree requirement that can be satisfied by a 500-level technical course.)

Specialization is achieved through the five electrical engineering elective courses, as well as other courses in electrical engineering or related subjects taken as technical, approved, or free electives. The School of Electrical Engineering offers more than thirty courses that are commonly taken as electives by undergraduates. Students with advanced standing frequently take one or more graduate-level courses prior to graduation.

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 technical elective categories, or serve as a prerequisite for an electrical engineering course. (It may count as a free elective, however, unless it must be repeated.)
3) Students must complete EE 301, 303, and 315 by the end of the first semester of the junior year, and accumulate at least 10 credits each semester toward the remaining degree requirements in the field program and technical elective categories.

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, including a minimum of two two-term course sequences in electrical engineering. (A list of approved course sequences is available from the Master of Electrical Engineering Program Office.) All but 8 credits of course work applied toward degree requirements must be at the graduate level (courses numbered 500 or above). 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. Students with special career goals, such as engineering management, may apply to use up to 8 credits of 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

D. L. Turcotte, chair; R. W. Allmendinger, M. Barazangi, W. A. Bassett, J. M. Bird, A. L. Bloom, L. D. Brown, L. M. Cathles, J. L. Cisne, B. L. Isacks, T. E. Jordan, D. E. Karig, S. Kaufman, R. W. Kay, J. E. Oliver, F. H. T. Rhodes, W. B. Travers, W. M. White

Bachelor of Science Curriculum

Study in geological sciences is offered for students who are preparing for careers in solid earth science, for those who want a broad background in the geological sciences as preparation for careers in other fields, and for those who want to combine geological training with other sciences such as agronomy, astronomy and space science, biological sciences, chemistry, economics, mathematics, physics, or various fields of engineering. The Department of Geological Sciences is organized as an intercollege department in the College of Arts and Sciences and the College of Engineering. College of Arts and Sciences students should consult that college's section on geological sciences as well as the course listing here.

Students in the College of Engineering who plan to enter the Field Program in Geological Sciences are required to take Geol 201 (Engr 201) during their freshman or sophomore year. Those interested in geobiology should also take Biological Sciences 101–103 and 102–104.

Geological Sciences requires the following courses for the major: Geol 210, 214, 326, 355, 356, 375, 388, and one other 300-, 400-, or 600-level course. A summer field geology course is also required.

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 and 375 should be taken relatively early in the major program as preparation for the summer field camp, which usually follows the junior year. Students with adequate preparation may attend field camp at an earlier time.

It is recommended that students intending to specialize in *geophysics* select most of their approved and technical electives from the following courses or their equivalents:

A&EP 333, Mechanics of Particles and Solid Bodies

A&EP 355, Intermediate Electromagnetism

A&EP 356, Intermediate Electrodynamics

A&EP 434, Continuum Physics

Phys 410, Advanced Experimental Physics

T&AM 310–311, Advanced Engineering Analysis I and II

It is recommended that students intending to specialize in *geochemistry* (including petrology and mineralogy) select most of their approved and technical electives from the following courses or their equivalents:

Chem 208, General Chemistry

Chem 287–288, Introductory Physical Chemistry

Chem 300, Quantitative Chemistry

Chem 301, Experimental Chemistry I

Chem 302, Experimental Chemistry II

Chem 303, Experimental Chemistry III

Chem 357–358, Introductory Organic Chemistry

Chem 389–390, Physical Chemistry I and II

MS&E 331, Structural Characterization and Properties of Materials

MS&E 335, Thermodynamics of Condensed Systems

It is recommended that students intending to specialize in *geobiology* select most of their approved and technical electives from the following courses or their equivalents:

Bio S 241, Introductory Botany

Bio S 274, The Vertebrates

Bio S 371, Human Paleontology

Bio S 373, The Invertebrates

Bio S 261, General Ecology

Bio S 448, Plant Evolution and the Fossil Record

Bio S 378, Organic Evolution

Chem 253, Elementary Organic Chemistry

It is recommended that students who want to pursue further training or immediate employment in *applied geology* (environmental and engineering geology, geohydrology, petroleum geology, or geological engineering) select most of their approved and technical electives from the following courses or their equivalents, with two of the four from the same field:

ABEN 371, Introduction to Hydrology and Ground-Water Pollution

ABEN 475, Environmental Systems Analysis

ABEN 671, Analysis of the Flow of Water and Chemicals in Soils

Agron 361, Genesis, Classification, and Geography of Soils

Agron 667, Soil Physics

Agron 366, Soil Chemistry

CEE 341, Introductory Soil Mechanics

CEE 611, Remote Sensing Applications

CEE 612, Physical Environment Evaluation

CEE 615, Digital Image Processing

CEE 640, Foundation Engineering

MS&E 331, Structural Characterization and Properties of Materials

MS&E 445, Mechanical Properties of Materials

CEE 331, Fluid Mechanics

CEE 332, Hydraulic Engineering

CEE 351, Environmental Quality Engineering

CEE 633, Flow in Porous Media and Groundwater

OR&IE 260, Introductory Engineering Probability

OR&IE 370, Introduction to Statistical Theory with Engineering Applications

Students intending to specialize in *economic geology* or pursue careers in the mining industries or mineral exploration should consider including economics courses among their humanities and social sciences electives and should select most of their approved and technical electives from the groups of courses listed above for geochemistry and applied geology plus the following additional courses:

CEE 654, Aquatic Chemistry

CEE 741, Rock Engineering

Students who want a more general background or who want to remain uncommitted with regard to specialty must choose at least two of their three approved electives from the same field, at a level comparable to the courses listed above. The technical electives may be chosen from offerings in geological sciences or in other science or engineering fields and should be at the 300 level or above. Outstanding students may request substitution of Geol 491 and 492, Undergraduate Research, for a fourth-year technical elective.

Students intending to pursue graduate study in geology are reminded that some graduate schools require proficiency in reading the scientific literature in one or two of the three languages, French, German, and Russian. Undergraduate preparation in at least one of these languages is therefore advantageous.

Master of Engineering (Geological Sciences Degree Program)

The Master of Engineering (Geological Sciences) degree is intended to provide future professional geologists with the geological and engineering background they will need to analyze and solve engineering problems that involve geological variables and concepts. Students may choose a program from one of several options, or tailor a program to meet their special interests with the help of a faculty adviser.

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, C. B. Carter, R. Dieckmann, E. Gianellis, D. T. Grubb, E. W. Hart, D. L. Kohlstedt, E. J. Kramer, C. Y. Li, J. W. Mayer, C. Ober, R. Raj, A. L. Ruoff, S. L. Sass, M. O. Thompson, Y. K. Vohra

Bachelor of Science Curriculum

Students who major in materials science and engineering are required to take MS&E 261, Introduction to Mechanical Properties of Materials, before the end of their junior year. They are strongly urged to take it as an engineering distribution course during their freshman or sophomore year. Students may enter the field after taking MS&E 262, Introduction to Electrical Properties of Materials, but they must still take MS&E 261 in order to graduate. Students who choose to major in materials science and engineering can concentrate in any one of the following areas of specialization: materials science, solid state, metallic materials, ceramic materials, polymeric materials, or electrical materials. Specialization is achieved through the selection of technical electives in the junior and senior years. The materials science and engineering field program leading to the Bachelor of Science degree consists of

Courses	*Credits*
MS&E 331, Structural Characterization of Materials	4
MS&E 332, Electrical and Magnetic Properties of Materials	3
MS&E 333, Research Involvement I, or a field-approved elective*	3
MS&E 334, Research Involvement II, or a field-approved elective*	3
MS&E 335 Thermodynamics of Condensed Systems	4
MS&E 336, Kinetics, Diffusion, and Phase Transformations	3
MS&E 441, Microprocessing of Materials	3
MS&E 442, Macroprocessing of Materials	3
MS&E 443/435, Senior Materials Laboratory I or Senior Thesis I	3/4
MS&E 444/436, Senior Materials Laboratory II or Senior Thesis II	3/4
MS&E 445, Mechanical Properties of Materials	3
MS&E 447, Materials Design Concepts I	2
MS&E 448, Materials Design Concepts II	2
	37/39

*These courses serve as two of the four required specialization courses. The other specialization courses are technical electives. The optional research involvement courses provide undergraduates with the opportunity to work with faculty members and their resesearch groups on current projects.

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 basic curriculum.
3) Complete MS&E 261 or 262 prior to entering the field.

The department's basic curriculum consists of all the required MS&E courses including MS&E 261 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. Students are urged to plan such curricula as early as possible.

Master of Engineering (Materials) Degree Program

Students who have completed a four-year undergraduate program in engineering or the physical sciences will be considered for admission to the M.Eng.(Materials) program, which includes a project and course work. The project, which must require individual effort and initiative, is worth 12 credits. It is carried out under the supervision of a member of the faculty, and is usually experimental, although it can also be analytical.

Courses, worth an additional 18 credits, may be selected from graduate-level courses in materials science and engineering or other courses approved by the faculty. These courses should be half MS&E courses and half technical electives. One 3-credit technical elective must be in advanced mathematics (modeling, computer applications, or computer modeling), beyond the MS&E undergraduate requirements. Other electives may be in MS&E or allied fields.

MECHANICAL AND AEROSPACE ENGINEERING

F. C. Moon, director; P. L. Auer, C. T. Avedisian, D. L. Bartel, J. F. Booker, A. H. Burstein, D. A. Caughey, B. J. Conta, P. R. Dawson, P. C. T. deBoer, A. R. George, F. C. Gouldin, J. C. Koechling, S. E. Landsberger, S. Leibovich, M. Y. Louge, J. L. Lumley, F. K. Moore, S. B. Pope, M. L. Psiaki, E. L. Resler, Jr., S. F. Shen, D. G. Shepherd, D. L. Taylor, K. E. Torrance, H. B. Voelcker, K. K. Wang, Z. Warhaft, G. G. Weber, R. L. Wehe, C. H. K. Williamson

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. Two main areas of concentration, corresponding to the two major streams of mechanical engineering technology, are offered in the field program.

Mechanical systems, design, and manufacturing is concerned with the design, analysis, testing, and manufacture of machinery, vehicles, devices, and systems. Particular areas of concentration include mechanical design and analysis, computer-aided design, vehicle engineering, composite materials, vibrations and control systems, biomechanics, and manufacturing engineering.

Engineering of fluids, energy, and heat-transfer systems has as its main concerns the experimental and theoretical aspects of fluid flow and heat transfer; the development of fossil, solar, and other energy sources for uses such as electric-power generation; industrial heating; terrestrial and aerospace transportation; and the use of heating, air conditioning, refrigeration, and noise- and pollution-control techniques to modify the human environment.

The undergraduate field program is a coordinated sequence of courses beginning in the sophomore year. During that year students who plan to enter the field of mechanical engineering take Engr 202 (also T&AM 202) as an engineering distribution course. They also take Engr 203 (also T&AM 203) which is a field requirement that may simultaneously satisfy Common Curriculum requirements as an approved (or free) elective. Both of these courses are prerequisites for courses to be taken during the junior year. During either the sophomore or junior year students take Engr 221 (also M&AE 221) and Engr 261 (also MS&E 261).

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 two technical electives, one approved elective, two free electives, and three humanities or social sciences courses.

2) Completion of the field requirements, which consist of ten required courses (beyond Engr 202 and 203, already mentioned), and three elective courses (9 credits). The ten additional required courses are

Engr 210, Introduction to Electrical Systems

Engr 221, Introduction to Thermodynamics

Engr 261, Introduction to Mechanical Properties of Materials

M&AE 312, Fundamentals of Manufacturing Processes

M&AE 323, Introduction to Fluid Mechanics

M&AE 324, Heat Transfer

M&AE 325, Mechanical Design and Analysis

M&AE 326, System Dynamics

M&AE 427, Mechanical Engineering Laboratory

M&AE 428, Engineering Design (required starting with the class of 1989)

If Engr 210 or 221 or 261 is taken as an engineering distribution course, the corresponding field requirement is replaced by an alternate technical elective. The three elective courses consist of one mathematics elective (3 credits), a field elective (3 credits), and a field design elective (3 credits). These electives are chosen from lists approved by the faculty of the Sibley School of Mechanical and Aerospace Engineering.

An additional graduation requirement of the field program is proof of elementary competence in technical drawing. 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) Engineering 102, Drawing and Engineering Design

c) another technical drawing course at Cornell, or

d) a departmental examination.

The proof is expected before completion of M&AE 325, Mechanical Design and Analysis.

The computer applications requirement of the Common Curriculum may be satisfied by several courses, including M&AE 389, 489, 575, and 670.

The requirements listed are those currently in effect. Requirements for classes earlier than 1989 differ somewhat from the ones listed.

Introduction to Electrical Systems (EE 210) may be replaced or supplemented by Introductory Electronics (Physics 360).

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

More-detailed materials describing the field program and possible concentrations may 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 a number of aerospace engineering electives such as M&AE 405, 506, 507, 530, 531, and 536. 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 want to develop a high level of competence in current technology and engineering design. This degree requires 30 credits of course work and is subject to the rules adopted by the Graduate Professional Program Committee. Because aerospace engineering is continually engaged in new areas, an essential guideline for the program is to reach beyond present-day practices and techniques. This is achieved by supplying the student with the fundamental background and the analytical techniques that will remain useful in all modern engineering developments. Aerospace students register for 1 credit a term on an S-U basis in M&AE Colloquium (M&AE 799). All other courses must have letter grades. To fulfill the design project requirement, students register for M&AE 592, Seminar and Design Project in Aerospace Engineering, for 2 credits a term. Other requirements are four aerospace core courses (minimum of 12 credits), two math courses (6 credits), and two technical electives (6 credits).

Aerospace Core Courses

3 credits:

M&AE 506, Aerospace Propulsion Systems

M&AE 507, Dynamics of Flight Vehicles

M&AE 530, Fluid Dynamics

M&AE 531, Boundary Layers

M&AE 536, Turbomachinery and Applications

M&AE 543, Combustion Processes

M&AE 559, Introduction to Controlled Fusion

M&AE 569, Mechanical and Aerospace Structures I

4 credits:

M&AE 601, Foundations of Fluid Dynamics and Aerodynamics

M&AE 602, Incompressible Aerodynamics

M&AE 603, Compressible Aerodynamics

M&AE 608, Physics of Fluids

M&AE 630, Atmospheric Turbulence and Micrometeorology

M&AE 639, Aerodynamic Noise Theory

M&AE 648, Seminar on Combustion

M&AE 651, Advanced Heat Transfer

M&AE 652, Thermodynamics and Phase Change Heat Transfer

M&AE 653, Experimental Methods in Fluid Mechanics, Heat Transfer, and Combustion

M&AE 670, Mechanical and Aerospace Structures II

M&AE 704, Theory of Viscous Flows

M&AE 732, Analysis of Turbulent Flows

M&AE 733, Stability of Fluid Flow

M&AE 734, Turbulence and Turbulent Flow

M&AE 736, Computational Aerodynamics

M&AE 737, Computational Heat Transfer and Fluid Mechanics

Nominations of Special Committee chair (adviser) must be filed with the Graduate School within three weeks of the start of classes. A formal selection of course work for the term must be filed within three weeks of the start of classes. A program of courses must be submitted for committee approval by the end of the first week of classes.

The school has particular strengths in the areas of fluid dynamics, aerodynamics, high-temperature gasdynamics, turbulence, chemical kinetics, aerodynamic noise, sonic boom, nonlinear waves, atmospheric flows, combustion processes in low-pollution engines, and solution of flow problems by numerical methods. Professional design projects may be arranged in any of these areas.

Master of Engineering (Mechanical) Degree Program

The M.Eng.(Mechanical) degree program provides a one-year course of study for those who want to develop a high level of competence in 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 areas include biomechanical engineering, combustion, energy and power systems, fluid mechanics, heat transfer, materials and manufacturing engineering, mechanical systems and design, and CAD/CAM (computer-aided design/computer-aided manufacturing). An individual student's curriculum includes a 4-credit design course, a major consisting of a minimum of 12 credits, and sufficient technical electives to meet the degree requirement of 30 credits. Students register for 1 credit per term on an S–U basis in M&AE Colloquium (M&AE 799). The design course (M&AE 590) is a formal consideration of the complete design process, including planning, cost analysis, and analytical methods. Students conduct one or more specific projects during the course. These projects may arise from individual faculty interests or from collaboration with industry. A student may replace the design course with an independent design project. Such a project must have a mechanical engineering design focus and have the close supervision of a faculty member.

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 overall objectives and a statement of purpose for the major, is submitted for approval to the Master of Engineering Committee by the end of the first week of class. Any subsequent changes must also be approved by this committee.

The courses that constitute the major must be graduate-level courses in mechanical and aerospace engineering or a closely related field such as theoretical and applied mechanics. At least 24 credits of the total for the degree must be in mechanical engineering or related areas, and in general all courses must be beyond the level of those required in the undergraduate program in mechanical engineering. Credit may be granted for an undergraduate, upper-level first course in some subject area if the student has done little or no previous work in that area, but such courses must have the special approval of the 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 enrolled in the M.Eng.(Mechanical) program may take courses that also satisfy the requirements of the Cornell Manufacturing Engineering and Productivity Program (COMEPP), leading to a special dean's certificate in manufacturing engineering.

NUCLEAR SCIENCE AND ENGINEERING

Faculty members in the graduate Field of Nuclear Science and Engineering who are most directly concerned with the Master of Engineering (Nuclear) curriculum include D. D. Clark (faculty representative), K. B. Cady, 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 Laboratory of Nuclear Engineering 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

A&EP 609, Low-Energy Nuclear Physics

A&EP 612, Nuclear Reactor Theory

A&EP 633, Nuclear Engineering

Technical elective

Spring term

A&EP 651, Nuclear Measurements Laboratory

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

EE 581, Introduction to Plasma Physics

EE 582, Advanced Plasma Physics

EE 589 Magnetohydrodynamics

EE 471, Feedback Control Systems

EE 572, Digital Control Systems

A&EP 636, Seminar on Thermonuclear Fusion Reactors

A&EP 638, Intense Pulsed Electron and Ion Beams: Physics and Technology

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

MS&E 459, Physics of Modern Materials Analysis

OPERATIONS RESEARCH AND INDUSTRIAL ENGINEERING

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

Bachelor of Science Curriculum in Operations Research and 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. An accelerated honors program is available for exceptional students interested in pursuing graduate studies.

A student who plans to enter the Field Program in Operations Research and Engineering should take Introductory Engineering Probability (Engr 260). For a student who has not taken Engr 260, entry into the field program in OR&E is possible only by permission of the associate director for undergraduate studies. In addition, it is recommended that Computers and Programming (CS 211 or Engr 211) be taken before entry into the OR&E field program. 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&E field program and the typical terms in which they are taken are as follows:

Term 5	*Credits*
OR&IE 320, Optimization I	4
OR&IE 350, Cost Accounting, Analysis, and Control	4
OR&IE 370, Introduction to Statistical Theory with Engineering Applications	4
CS 211, Computers and Programming*	3
Course in humanities and social sciences	3

*If CS 211 has already been taken, an appropriate 3- or 4-credit technical elective must be substituted.

Term 6	
OR&IE 321, Optimization II	4
OR&IE 361, Introductory Engineering Stochastic Processes	4
OR&IE 410, Industrial Systems Analysis	4
Behavioral science†	3
Course in humanities and social sciences	3

†The behavioral science requirement can be satisfied by any one of several courses of an advanced nature, including Graduate School of Management (GSM) NCC 504 (offered only in the fall), which is recommended for those contemplating the pursuit of a graduate business degree, and Industrial and Labor Relations 120, 121, 151, 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, Digital Systems Simulation	4
Three upperclass OR&IE electives as described below	9
Two technical electives	6
Two courses in humanities and social sciences	6
Two free electives	6

Available OR&E electives are as follows:

Industrial systems: OR&IE 416, 417, 421, 451, 525, and 562 and GSM NBA 601 and 641*

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

Applied probability and statistics: OR&IE 462, 472, 475, 476, 561, 563, 575, and 577

*No more than one course in the Graduate School of Management may be taken as an OR&E elective.

Scholastic requirements for the field are a passing grade in every course, 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.

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 of new or improved man-machine systems, information systems, and control systems.

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 Engineering. Also welcome are requests for admission from Cornell undergraduates in engineering programs other than OR&E or from qualified non-Cornellians. To ensure completion of the program in one calendar year, the entering student should have completed courses in probability theory and basic probabilistic models and in computer programming and should have acquired some fundamental knowledge of economic concepts required for decision making. Students interested in the manufacturing systems engineering option and the manufacturing internship program should obtain further information regarding program requirements from the office of the Cornell Manufacturing Engineering and Productivity Program, 319 Upson Hall.

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

Fall term	*Credits*
OR&IE 516, Case Studies	4
OR&IE 893, Applied OR&IE Colloquium	1
OR&IE 599, Project	1
Three technical electives	9
Spring term	
OR&IE 894, Applied OR&IE Colloquium	1
OR&IE 599, Project	minimum of 4
Three technical electives	9

The electives specified above will normally be chosen from graduate courses offered by the School of Operations Research and Industrial Engineering. 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 370, 520, and 523 will take technical electives in their place):

Fall term	*Credits*
OR&IE 370, Introduction to Statistical Theory with Engineering Applications	4
OR&IE 520, Operations Research I	4
OR&IE 516, Case Studies	4
OR&IE 580, Digital Systems Simulation	4
OR&IE 893, Applied OR&IE Colloquium	1
OR&IE 599, Project	1
Spring term	
OR&IE 523, Introduction to Stochastic Modeling	4
OR&IE 894, Applied OR&IE Colloquium	1
OR&IE 599, Project	minimum of 4
Two technical electives	6

Students fulfill the project requirement by working as part of a group of no more than four students on an operational systems problem that actually exists in some organization. Appropriate problems are suggested by manufacturing firms, retailing organizations, service organizations, government agencies, and educational institutions.

Cooperative Program with the Johnson Graduate School of Management

Undergraduates majoring in operations research and 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&E 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, Upson Hall, and at the admissions office of the Johnson Graduate School of Management.

STATISTICS CENTER

The Cornell Statistics Center coordinates a university-wide program in statistics and probability. Students interested in graduate study in probability and statistics should apply to the Field of Statistics or to one of the other graduate fields that offer related coursework.

A list of courses in probability and statistics recommended for graduate students in the Field of Statistics can be found in the description of the Cornell Center for Statistics in the section "Interdisciplinary Centers and Programs." Further information can be obtained from the director of the Statistics Center, Lawrence Brown, or the field representative for statistics, George Casella, both at 272 Caldwell Hall.

THEORETICAL AND APPLIED MECHANICS

J. A. Burns, chair; H. D. Conway, J. M. Guckenheimer, E. W. Hart, T. J. Healey, P. J. Holmes, C. Y. Hui, J. T. Jenkins, R. H. Lance, S. Mukherjee, Y. H. Pao, R. H. Rand, P. Rosakis, A. L. Ruina, W. H. Sachse, 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 (Mechanics) Degree Program

This program focuses on the mechanical behavior of advanced composite materials and structures. It is designed for students who have completed a four-year undergraduate program in a field such as mechanical, aerospace, structural, materials, or biomedical engineering, who wish to develop a high level of competence in the mechanics of composites. It leads to the professional Master of Engineering degree, whose requirements can be met in one year.

The curriculum is composed of courses that explore the nature of modern composite materials and provide students with a broad background in the fundamentals as well as an introduction to techniques that will be useful in subsequent work. 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 501, 502, 555, or 655. 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 listed below or others approved by the student's adviser.

The Department of Theoretical and Applied Mechanics has several laboratories equipped for the mechanical testing of composite materials and structures. Extensive computing resources are available for numerical computations, design, or other research activities. 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. All of these facilities are at the disposal of students carrying out professional design projects.

Core courses in the M.Eng.(Mechanics) program are:

Course	*Credits*
T&AM 555, Introduction to Composite Materials	3
T&AM 655, Advanced Composite Materials and Structures	3
T&AM 663, Solid Mechanics I	4
T&AM 501, Topics in Composites I	1–3
Selected from the following:	
Analysis of Composite Structures	
Mechanical Testing of Composite Constituents	
Fracture Testing of Composites	
Reliability Models for Composites	
Design Principles for Composite Structures	
Biological Composites	
T&AM 502, Topics in Composites II	1–3
Selected from the following:	
Effective Properties of Composites	
Interface Failure and Fracture Processes in Composites	
Boundary-Element Methods for Composites	
Nondestructive Testing of Composites	
Software for Composite Design	
Novel Composite Structures	
MS&E 450, Physical Metallurgy	3
MS&E 452, Properties of Solid Polymers	3
MS&E 605, Plastic Flow and Fracture of Materials	3
M&AE 465, Biomechanical Systems: Analysis and Design	3
M&AE 569, Mechanical and Aerospace Structures	3
M&AE 670, Mechanical and Aerospace Structures II (Finite-Element Methods)	4
CEE 770, Engineering Fracture Methods	3
CEE 772, Finite-Element Analysis	3
T&AM 591, Master of Engineering Design Project I	3–5
T&AM 592, Master of Engineering Design Project II	5–10

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 Common Courses	Engr
Agricultural Engineering	ABEN
Applied and Engineering Physics	A&EP
Chemical Engineering	Chem E
Civil and Environmental Engineering	CEE
Computer Science	CS
Electrical Engineering	EE
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

Courses of General Interest

100 Introduction to Computer Programming (also CS 100)

Fall, spring, summer. 4 credits. The course content is the same as that of CS 100.

2 lecs, 1 rec (optional), 3 evening exams. 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 Pascal. The course does not presume previous programming experience. An introduction to numerical computing is included, although no college-level mathematics is presumed. Programming assignments are tested and run on interactive, stand-alone microcomputers.

101 The Computer Age (also CS 101)
Fall, summer. 3 credits. Credit is granted for both CS 100 and 101 only if 101 is taken first.
2 lecs, 1 rec, 1 evening exam.
An introduction to computer science and programming for students in nontechnical areas. The aims of the course are to acquaint the student with the major ideas in computer science and to develop an appreciation of algorithmic thinking. Topics include the history of computation; microtechnology; the retrieval and transmission of information; scientific computing; computer graphics, art, and music; robotics, natural-language processing, and machine intelligence. Students become acquainted with the notion of an algorithm by writing several programs in Pascal or LISP and testing them on microcomputers. The amount of programming is about half that taught in Engr 100. Each student writes a term paper on some aspect of computing.

102 Drawing and Engineering Design (also M&AE 102)
Fall, spring. 1 credit. Half-term course offered twice each semester. Enrollment limited to thirty students each half term. Recommended for students without previous mechanical drawing experience. S-U grades optional.
2 lecs, 1 lab.
Introduction to drawing and graphic techniques useful in design, analysis, and presentation of ideas. Use of computer-aided drafting software is introduced in the final design project.

250 Technology in Western Society (also EE 250)
Fall. 3 credits. Meets humanities distribution requirement.
R. Kline.
The interaction between technology and Western society from the earliest times to the present, focusing on Western Europe up to the British industrial revolution in the late eighteenth century, and on the United States thereafter. Topics include the economic and social aspects of industrialization; the myths of heroic inventors like Morse, Edison, and Ford; the government's promotion and regulation of technology through such measures as the patent system, the funding of research and development, and regulatory legislation; the origins of modern systems of mass production; and the spread of the automobile and microelectronics cultures in the United States.

281 Structures and Machines in Urban Society (also T&AM 281)
Fall. 3 credits.
R. Lance.
Major technological advances during the hundred years since the Industrial Revolution and how they have shaped urban society. Development and use of the steam engine and the suspension bridge; their modern counterparts. Transportation, electricity, and communication systems. Social, symbolic, and scientific perspectives. Simple formulas for designing and analyzing machines and structures. Illustrated lectures. Readings include the writings of engineers as well as social and scientific critics.

292 The Electrical and Electronic Revolutions (also EE 292)
Spring. 3 credits. Approved for humanities distribution, not for EE or as a technical elective.
R. Kline.
A survey of the history of electricity in society from the telegraph to the personal computer. The course considers both the technical and social history of telecommunication, the electric power industry, microelectronics, and computers. Emphasis is placed on the changing relationship between science and technology, the institutional context of research and development, and the electrical engineer and society.

301 Writing in Engineering
Fall and spring. Can be used to satisfy requirements in expressive arts or as a free or approved elective.
Offered only in conjunction with "writing-intensive" engineering courses. Faculty from the college's Writing Program prepare students for writing assignments and guide them through composing, drafting, editing, and revising. Strengthens understanding of the course materials and communication skills. Work is discussed in class and in individual conferences. May be taken more than once, with different engineering courses, but may not be taken independently.

321 Microeconomic Analysis (also CEE 321 and Economics 313, lecture 5)
Fall. 4 credits. Prerequisite: one semester of calculus. A social science elective for engineering students.
R. E. Schuler.
Intermediate microeconomic analysis similar to Economics 313 but emphasizing mathematical techniques and engineering-design implications. Theory of consumer choice and efficient production; analysis of monopoly and competitive markets; theories of distribution, market equilibrium, and welfare economics.

322 Economic Analysis of Government (also CEE 322 and Economics 308)
Spring. 4 credits. Prerequisites: one semester of calculus, plus CEE 321 or Economics 313. A social science elective for engineering students.
R. E. Schuler.
Analysis of government intervention in a market economy and implications for engineering planning and design. Market imperfections, public goods and public decision making, public finance, cost-benefit analysis of government projects, environmental regulation, risk management, and macroeconomic topics.

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 methods of operations research. Intended to give students a working knowledge of money management and how to make economic comparisons of alternative engineering designs or projects. Project management, inflation, taxation, depreciation, financial planning, and basic operations-research techniques of simulation and optimization are introduced and applied to economic investment problems.

350 Engineering Communications
Fall and spring. 3 credits. Limited to 17 students.
Instruction and practice in written, oral, and visual presentation. Communications in real-life engineering contexts are analyzed; assignments include case studies or problems which resemble actual engineering work. The class also considers the social and ethical implications of communications. By composing letters, memoranda, summaries, instructions, explanations, proposals, and reports, students learn to address audiences having different levels of technical expertise. Some assignments include oral or graphic presentation. The goal throughout is clear, well-organized, responsible, and graceful professional communication.

355 Understanding Cultural Differences in the Engineering Work Environment
Fall and spring. 1 credit. Open to sophomores, juniors, seniors, and graduate students from all Cornell academic units.
E. P. Gordon.
This seminar prepares students for the variety of cultural experiences they will encounter in industry and improves their opportunities to succeed in a multicultural work environment. Students explore the customs, values, and beliefs of different cultures. Much attention is given to ways of communicating across cultures, techniques for teamwork and building relationships with supervisors and peers, and skills for taking advantage of the positive opportunities inherent in a diverse work force. Both corporate professionals and Cornell faculty members from throughout the university offer lectures.

360 Ethical Issues in Engineering
Spring. 3 credits. A social-science elective for engineering students. Open to juniors and seniors.
3 lecs.
A discussion of ethical issues encountered in engineering practice, such as the rights of engineers in corporations, responsibility for harmful actions, whistleblowing, conflicts of interest, and decision making based on cost-benefit analysis. Use of codes of ethics of professional engineering societies and ethical theory to help sort conflicting obligations the engineer may feel toward public safety, professional standards, employers, colleagues, and family. Students will present a case study to the class, along the lines of the Space-Shuttle Challenger disaster, the Kansas City Hyatt-Regency Hotel walkway failure, or the Cornell computer "worm".

[400 Science, Risk, and Public Policy (also T&AM 400 and Economics 358)
Fall. 3 credits. Not offered 1990–91.
The scientific and humanistic bases of risk assessment and management, examined from a variety of perspectives. Emphasis on the measurement of natural and social phenomena; the psychological and political components in assessing the human and economic costs of risk; and the policies that individuals, institutions, and governments establish to manage risks.]

Introduction to Engineering Courses

110 The Laser and Its Applications in Science, Technology, and Medicine (also A&EP 110)
Fall, spring. 3 credits.
2 lecs, 1 lab.
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-induced chemistry, Raman spectroscopy, frequency doubling, and interferometry. Guest lectures by prominent medical and industrial scientists introduce students to current fields of laser application and research.

111 Elements of Materials Science and Engineering (also MS&E 201)
Fall. 3 credits.
Relations between atomic structure and macroscopic properties of such diverse materials as metals, ceramics, and polymers. Properties discussed include magnetism, superconductivity, insulation, semiconductivity, mechanical strength, and plasticity. Design problems involving microelectronics, superconducting power transmission lines, synthetic bones and joints, ceramic engines, etc.

112 Introduction to Chemical Engineering (also Chem E 112)
Fall, spring. 3 credits. Limited to freshmen.
2 lecs, 1 rec. F. Rodriguez, M. L. Shuler.
This course is designed to acquaint students with the scope of chemical engineering. Topics such as polymers, fluid flow, and plant design will be introduced at an elementary level. Quantitative discussions buttressed by lecture demonstrations will show how the engineering approach differs from a purely scientific one. The rapid solving of numerical problems is emphasized in homework and on tests.

113 Computer-aided Design in Environmental Systems (also CEE 113)
Fall. 3 credits.
2 lecs, 1 sec. C. A. Shoemaker.
Planning, design, and management of environmental systems. Emphasis on use of computer-aided techniques, including interactive computer graphics. Sample problems will address public-systems issues and water-quality management. The objective of the course is to provide students with an opportunity to experiment with alternative design and management strategies in several areas of environmental engineering.

115 Engineering Application of Operations Research (also OR&IE 115)
Fall, spring. 3 credits.
2 lecs, 1 lab.
Techniques for optimal decision making and engineering design. Computer graphics and mathematical modeling. Allocation of scarce resources, simulation of complex systems, design and analysis of networks, strategies in competitive games. Engineering applications and problem solving will be stressed.

116 Modern Structures (also CEE 116)
Fall, spring. 3 credits.
2 lecs, 1 sec. M. Sansalone.
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 are discussed. The Computer-Aided Design Instructional Facility (CADIF) and the Craig Miller Laboratory for Structural Modeling in Hollister Hall are used to demonstrate how engineering materials and structures behave under load. A semester project involves the design and construction of a small balsa-wood bridge.

117 Introduction to Mechanical Engineering (also M&AE 117)
Fall. 3 credits. Consists of two half-term minicourses chosen from a list of three. Two of these minicourses alternate; the third (Drawing and Engineering Design) is offered every half term but has limited enrollment.
2 lecs, 1 lab.
Drawing and Engineering Design (see Engr 102) will enable students without prior mechanical drawing experience to understand and create basic engineering graphics. The other two minicourses provide an introduction to topics of current interest typifying two broad areas within mechanical engineering: fluid and thermal sciences, and mechanical systems and manufacturing. Emphasis is on the practical applications of this knowledge.

119 Introduction to Manufacturing Engineering (also M&AE 119 and OR&IE 119)
Spring. 3 credits.
2 lecs, 1 lab.
Engineering considerations in the design, manufacture, distribution, and service of products. Transformation from functional requirements to material, processing, assembly, and inspection requirements; design and management of manufacturing facilities and distribution channels.

121 Fission, Fusion, and Radiation (also NS&E 121)
Spring. 3 credits.
2 lecs, 1 lab demonstration.
A lecture, demonstration, and laboratory course on (1) the physical nature and biological effects of nuclear radiation; (2) the benefits and hazards of nuclear energy; (3) light-water reactors, breeder reactors, and fusion reactors; and (4) the uses of nuclear radiation in physical and biological research. The laboratory work and demonstrations involve criticality and the control of Cornell's two research reactors; detection of, and protection against, nuclear radiation; neutron activation analysis using gamma-ray spectroscopy; and plasma sources and devices.

123 Sensors and Actuators
Fall. 3 credits.
2 lecs, 1 lab.
A sensor or an actuator is the element by which information is converted from one form of energy to another. It is the key component in all measurement and control systems. This course will focus on the operational features of a wide variety of sensors and actuators that are used in scientific and engineering metrology, in industrial process control applications, and in consumer products. The devices may be based on electrical, mechanical, acoustical, optical, and thermal phenomena. Students will measure the parameters of various thermomechanical sensors and actuators and they will be expected to design, fabricate, and verify the operation of a sensor meeting specific design objectives.

172 Introduction to Artificial Intelligence
Spring. 4 credits. Recommended: CS 100 or 101, or equivalent computer experience. Enrollment my be limited.
3 lecs, 2 evening exams.
A hands-on introduction to concepts in artificial intelligence. Topics may include heuristic search, game playing, automated theorem proving, natural-language processing, expert systems, neural networks and/or machine learning. Students will use workstation environments to gain software laboratory experience. Interested students need not be proficient programmers to take this class.

185 Art, Isotopes, and Analysis (also MS&E 285, Physics 200, Archaeology 285, English 285, and Art 372)
Spring. 3 credits.
3 lecs. J. W. Mayer, S. Taft, D. Eddy.
The analysis of paintings and rare books and the physical concepts underlying modern analytical techniques. Each week a work of art will be discussed, focusing on the historical and technical aspects of its creation and modern analysis of it. Visual, infra-red, and x-ray examinations provide insight into the physical properties. Pigments are identified by the radiation emitted in electronic transitions. The ratio of isotopes can be used to identify the geographical origin of a particular pigment and also as a dating method. The same analytical techniques are also discussed from the viewpoint of archaeological investigations.

Engineering Distribution Courses

201 Introduction to the Physics and Chemistry of the Earth (also Geol 201)
Spring. 3 credits. Prerequisites: Mathematics 191, Physics 112, and Chemistry 207.
2 lecs; 1 rec, lab, or field trip.
L. M. Cathles.
Formation of the solar system, accretion and evolution of the earth, radioactive isotopes and the geological time scale, rocks and minerals, the continents and the oceans, erosion and sedimentation, weathering processes, the earth as a heat engine, volcanism, seismology, gravity, magnetism, plate tectonics, deformation of the earth's crust, comparative planetology.

202 Mechanics of Solids
Fall, spring. 3 credits. Prerequisite: coregistration in Mathematics 293.
2 lecs, 1 rec, 4 labs each semester, evening exams.
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.

203 Dynamics
Fall, spring. 3 credits. Prerequisite: coregistration in Mathematics 294.
2 lecs, 1 rec, 4 labs each semester, evening exams.
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.

210 Introduction to Electrical Systems (also EE 210)
Fall, spring. 3 credits. Prerequisites or corequisites: Mathematics 293 and Physics 213.
3 lecs and optional tutorial secs.
Circuit elements and laws, analysis techniques, operational amplifiers. Response of linear systems, with an introduction to complex frequency and phasors, forced response, average power, transfer function, pole-zero concepts, and the frequency spectrum. Terminal characteristics of diodes and transistors, linear models, bias circuits, and frequency response of small-signal amplifiers.

211 Computers and Programming (also CS 211)
Fall, spring, summer. 3 credits. Prerequisite: CS 100 or equivalent programming experience.
2 lecs, 1 rec, 2 evening exams.
Intermediate programming in a high-level language and introduction to computer science. Topics include program development, proofs of program correctness, program structure, recursion, abstract data types, data structures, and analysis of algorithms. Pascal is the principal programming language.

219, 220 Mass and Energy Balances (also Chem E 219, 220)
219, fall; 220, spring, summer. 3 credits. Corequisite: physical or organic chemistry; 220 is intended for transfer students who cannot take 219 and requires permission of instructor.
A. Panagiotopoulos, G. F. Scheele.
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. Humidification processes. Chem E 220 differs from 219 in that it uses *only self-paced audiovisual instruction at the convenience of the student.* A minimum of seventy clock hours of audiovisual instruction is required to master the subject matter. Student performance in 220 is evaluated by nine tests.

221 Thermodynamics
Fall, spring. 3 credits. Prerequisites: Mathematics 192 and Physics 112.
3 lecs.
The definitions, concepts, and laws of thermodynamics. Applications to ideal and real gases, multiphase pure substances, gaseous reactions. Heat-engine and heat-pump cycles, with an introduction to energy-conversion systems.

222 Introduction to Scientific Computation (also CS 222)
Spring. 3 credits. Prerequisites: CS 100 and Mathematics 112, 122, or 192.
2 lecs, 3 evening exams.
Students write FORTRAN programs to solve representative problems from elementary calculus. Emphasis is on the design of numerical software that is efficient, reliable, stable, and portable. Special topics include supercomputing and parallel computation.

241 Engineering Computation (also CEE 241)
Fall, spring. 3 credits. Prerequisites: CS 100 and Mathematics 293. Corequisite: Mathematics 294.
J. R. Stedinger, J. F. Abel.
This course develops FORTRAN programming proficiency and provides exposure to engineering computation. The art of top-down, modular program design is illustrated with engineering applications. Included are numerical methods for solving engineering problems such as Taylor-series approximations, truncation and round-off errors, roots of functions, solution of simultaneous linear equations, interpolation, numerical differentiation and integration, the solution of ordinary differential equations, and the context and solution of partial differential equations. Applications are drawn from different areas of engineering.

260 Introductory Engineering Probability (also OR&IE 260)
Fall, spring. 3 credits. Prerequisite: first-year calculus.
3 lecs.
The basic tools of probability and their use in engineering. This may be the last course in probability for some students, or it may be followed by OR&IE 361, Introductory Engineering, Stochastic Processes I, or by OR&IE 370, Introduction to Statistical Theory with Engineering Applications. Definition of probability; random variables; probability distributions, density functions, expected values; jointly distributed random variables; distributions such as the binomial, Poisson, and exponential that are important in engineering and how they arise in practice; limit theorems.

261 Introduction to Mechanical Properties of Materials
Fall, spring. 3 credits.
2 lecs, 1 rec or lab.
The relation 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, hardness, fracture strength, creep resistance, or fatigue resistance. Flaw-tolerant design methods using fracture mechanics.

262 Introduction to Electrical Properties of Materials
Spring. 3 credits.
2 lecs, 1 rec or lab.
Electrical and structural properties of semiconductors, the operation of p-n junctions and transistors, and the processing methods used to form modern integrated circuits. Electrical conduction in metal films, semiconductors, bipolar and field-effect transistors and light-emitting diodes. Diffusion, ion implantation, oxidation, metallization, and other process steps in fabricating semiconductor devices. Interplay between structural and electrical properties and their application to the design of semiconductor devices and integrated circuits.

264 Computerized-Instrumentation Design (also A&EP 264)
Fall, spring. 3 credits. Prerequisites: Engr 100 or CS 100.
1 lec, 1 lab.
Design techniques for incorporating small computers into experimental apparatus. Experiments in elementary physics are performed with appropriate sensors wired to computer interfaces, under program control that employs routines written in BASIC and ASSEMBLY languages. Analog-to-digital converters, digital-to-analog converters, optical encoders, and stepping motors are used. Graphic display of data and theoretical fit are emphasized.

270 Basic Engineering Probability and Statistics
Fall, spring. 3 credits. Students who intend to enter the upperclass Field Program in Operations Research and Industrial Engineering should take Engr 260 instead of this course. Prerequisite: first-year calculus.
3 lecs, evening prelims.
At the end of this course a student should command a working knowledge of basic probability and statistics as they apply to engineering work. For students who want to have greater depth in probability and statistics, a course in probability (OR&IE 260) followed by a course in statistics (OR&IE 370) is recommended.

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.

APPLIED AND ENGINEERING PHYSICS

110 The Laser and Its Applications in Science, Technology, and Medicine (also Engr 110)
Fall, spring. 3 credits. This is a course in the Introduction to Engineering series.
2 lecs, 1 lab.
For description see Engineering Common Courses.

264 Computerized-Instrumentation Design (also Engr 264)
Fall, spring. 3 credits. Prerequisites: Engr 100 or CS 100.
1 lec, 1 lab.
For description see Engineering Common Courses.

303 Introduction to Nuclear Science and Engineering I (also NS&E 303)
Fall. 3 credits. Prerequisite: Physics 214 or Mathematics 294.
3 lecs.
For description see NS&E 303.

321 Mathematical Physics I
Fall. 4 credits. Prerequisite: Math 294. Intended for upper-level undergraduates in the physical sciences.
4 lecs.
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, Green's functions, Bessel functions. Texts: *Mathematical Methods for Physicists*, by Arfken; *Mathematical Physics*, by Butkov.

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.
4 lecs.
Partial differential equations, 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.

333 Mechanics of Particles and Solid Bodies
Fall, summer. 4 credits. Prerequisites: Physics 112 or 116 and coregistration in A&EP 321 or equivalent or permission of instructor.
3 lecs, 1 rec.
Newton's mechanics; linear oscillations; Lagrangian and Hamiltonian formalism for generalized coordinates and constrained motion; 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 physical concepts and applications. (On the level of *Classical Dynamics*, by Marion).

355 Intermediate Electromagnetism
Fall, summer. 4 credits. Prerequisites: Physics 214 or 217 and coregistration in A&EP 321 or equivalent, or permission of instructor.
3 lecs, 1 rec.
Topics: vector calculus, electrostatics, magnetostatics, and induction phenomena; solutions to Laplace's equation in various geometries, electric and magnetic materials, electric and magnetic forces, energy storage, skin effect, quasistatics. Emphasis on physical concepts and applications to design of high-voltage generators, electron guns, and particle accelerators.

356 Intermediate Electrodynamics
Spring. 4 credits. Prerequisite: A&EP 355 and coregistration in A&EP 322 or equivalent, or permission of instructor.
3 lecs, 1 rec.
Topics: electromagnetic wave phenomena, transmission lines, waveguides, dispersive media, scattering, radiation, reciprocity, physical optics, special relativity. Emphasis on physical concepts and their application to the design of microwave circuits, antenna arrays, and optically coupled systems.

361 Introductory Quantum Mechanics
Spring. 4 credits. Prerequisites: A&EP 333 or Physics 318; coregistration in A&EP 322 or equivalent and in A&EP 356 or Physics 326.
3 lecs, 1 rec.
A first course in the systematic theory of quantum phenomena. Topics include the harmonic oscillator, the Dirac formalism, angular momentum, the hydrogen atom, and perturbation theory. Analytical solutions of the Schroedinger equation are supplemented with numerical solutions on a microcomputer.

363 Electronic Circuits (also Physics 360)
Fall, spring, summer. 4 credits. Prerequisite: Physics 208 or 213 or permission of instructor; no previous experience with electronics is assumed. Fall term is generally less crowded.
1 lec, 2 labs.
This laboratory course focuses on designing, building, and testing analog, digital, and microprocessor-based circuits that are useful in electronic instrumentation. Analog topics include basic circuit concepts, applications of operational amplifiers in linear circuits, oscillators and comparators, transistor circuits and diodes in power supplies, waveform-shaping circuits, and protective circuits. Students also design and build digital circuits that incorporate Schmidt triggers, comparators, and combinatorial and sequential logic using meduim-scale integrated circuits. The above circuits are also interfaced to a microprocessor whose architecture, machine instruction set, and programming principles are studied. At the level of *Introductory Electronics for Scientists and Engineers*, 2d ed., by R. E. Simpson.

423 Statistical Thermodynamics
Fall. 4 credits. Prerequisite: Introductory three-semester physics sequence plus one year of junior-level mathematics.
3 lecs, 1 rec.
Quantum statistical basis for equilibrium thermodynamics, canonical and grand canonical ensembles, and partition functions. Quantum and classical ideal gases and paramagnetic systems. Fermi-Dirac, Bose-Einstein, and Maxwell-Boltzmann statistics. Introduction to systems of interacting particles. At the level of *Thermal Physics*, by Kittel, and *Statistical Physics*, by Mandl.

434 Continuum Physics
Spring. 4 credits. Prerequisites: A&EP 333 and 356 or equivalent.
3 lecs, 1 rec.
Local conservation laws; stress, strain, and rate-of-strain tensors; equations of motion for elastic and viscous response; waves in solids and fluids; dislocations; ideal fluids, potential flow, Bernouli's equation, vorticity and circulation, lift; viscous incompressible flow and the Navier-Stokes equations, Reynolds number, Poiseuille flow in a pipe, Stokes drag on a sphere; boundary layers, Blasius equations; flow instabilities, Rayleigh-Benard convection and the onset of chaotic flow. Introduction to turbulent flow.

436 Physical and Integrated Optics
Spring. 4 credits. Prerequisite: A&EP 355.
3 lecs, 1 lab.
The fundamentals of optics: diffraction, polarization, interference, birefringence, scattering, Fourier optics. Applications to optical waveguides, nonlinear optics, integrated optics, optical storage, coherent detection, optical communications. Emphasis on hands-on experimental laboratory demonstrations and computer synthesis of optical phenomena.

490 Informal Study in Engineering Physics
Credit to be arranged.
Laboratory or theoretical work in any branch of engineering physics under the direction of a member of the staff. The study can take a number for forms; for example, design of laboratory apparatus, performance of laboratory measurements, or theoretical design or analysis. Details to be arranged with respective faculty member.

606 Introduction to Plasma Physics (also EE 581)
Fall. 4 credits. Prerequisites: A&EP 355 or 356 or equivalent. Open to fourth-year students with permission of instructor.
3 lecs.
Motion of charged particles in fields, collisions, plasma waves, Boltzmann equation, microinstabilities, Landau damping, introduction to kinetic theory, introduction to M.H.D., single-fluid equations, Tokamak equilibrium, and stability.

607 Advanced Plasma Physics (also EE 582)
Spring. 4 credits. Prerequisite: A&EP 606.
3 lecs.
Boltzmann and Vlasov equations; waves in hot plasmas; Landau damping, microinstabilities; drift waves, low-frequency stability, collisional effects; method of dressed test particles; high-frequency conductivity and fluctuations; neoclassical toroidal diffusion, high-powered beams.

608 Plasma Astrophysics (also Astronomy 660)
Spring. 2 credits.
Selected topics discussed in detail: (a) the solar corona and the solar wind, (b) hydrodynamic and magnetohydrodynamic flows around compact objects in galactic nuclei, (c) global electrodynamics of double radio sources.

609 Low-Energy Nuclear Physics
Fall. 4 credits. Prerequisite: an introductory course in modern physics, including quantum mechanics.
3 lecs.
The nuclear interaction. Properties of ground and excited states of nuclei; models of nuclear structure; alpha, beta, gamma radioactivity; low-energy nuclear reactions—resonant and nonresonant scattering, absorption, and fission. At the level of *Introduction to Nuclear Physics*, by Enge.

612 Nuclear Reactor Theory
Fall. 4 credits. Prerequisites: a year of advanced calculus and some nuclear physics.
3 lecs.
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.

615 Membrane Biophysics
Fall. 3 credits.
Molecular structure and supramolecular organization of cell membranes. Model membranes and membrane models. Molecular mechanisms of membrane transport, electrophysiology and cell-cell interaction, molecular channels. Receptors and transmembrane ion channels, molecular basis for Hodgkin-Huxley theory, single-channel recording, sensory transduction mechanisms. Physical probes of membrane processes. Dynamics of membrane processes, lateral mobility, diffusion, and flow. Some current problems in cell-surface function and organization of specialized membrane macrostructures.

633 Nuclear Engineering
Fall. 4 credits. Prerequisite: introductory course in nuclear engineering.
The fundamentals of nuclear reactor engineering, reactor siting and safety, fluid flow and heat transfer, control, and radiation protection.

634 Nuclear Engineering Design Seminar
Spring. 4 credits. Prerequisite: A&EP 633.
A group design study of a selected nuclear system. Emphasis is on safety, siting, and radiation protection in the design of nuclear systems.

636 Seminar on Thermonuclear Fusion Reactors
Fall. 3 credits. Prerequisite: basic course in plasma physics or nuclear reactor engineering, or permission of instructor. Offered alternate years.
Analysis of various technological and engineering problems in design and construction of fusion reactors. Topics include basic reactor schemes, materials, mechanical and heat-transfer problems, radiation and safety, superconducting magnets, energy conversion, plasma impurities, and economics.

638 Intense Pulsed Electron and Ion Beams: Physics and Technology
Spring. 2 credits. Prerequisites: A&EP 606 (EE 581) and 607 (EE 582) or equivalent, or permission of instructor. Offered alternate years.
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.

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, which has the same lecture but has only one lab period, is intended for students in non-nuclear fields in which nuclear methods are used

One 2-hour lecture and two 1/2 hour labs. D. D. Clark.

Lectures on interaction of radiation with matter, radiation protection, and nuclear instruments and methods. About fifteen experiments are available in radiation detection, attenuation, and measurement; electronic instrumentation, including computerized systems; activation analysis; neutron radiography; neutron moderation and reactor physics; neutron diffraction; and low-energy nuclear physics with neutron beams. The TRIGA reactor and the Zero Power Reactor critical facility are used. Students select seven or eight experiments to meet their interests and needs. At the level of *Radiation Detection and Measurement*, by Knoll.

661 Microcharacterization
Fall. 3 credits. Prerequisites: Physics 112, 213, and 214, or an introductory course in modern physics.
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 characterizatation is performed, the methodology used in performing the characterization, the advantages and limitations of each technique, and the instrumentation involved in each characterization method.

662 Microprocessing and Microfabrication of Materials
Spring. 3–4 credits (3 credits plus 1 credit for optional laboratory).

Several field trips.

An introduction to the fundamentals of fabricating and patterning thin-film materials and surfaces, with emphasis on electronic materials. 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.

681–689 Special Topics in Applied Physics
Topics, instructors, and credits to be announced each term. Typical topics include quantum superconducting devices, physics of submicron conductors, nonlinear fluctuators, biophysical processes, molecular fluorescence.

711 Principles of Diffraction (also MS&E 610)
Fall. 3 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.

751, 752 Project
751, fall; 752, spring. Credit to be arranged. Required for candidates for the M.Eng. (Engineering Physics) degree.
Informal study under the direction of a member of the university faculty. Students are offered research experience through work on a special problem related to their field of interest.

753 Special Topics Seminar in Applied Physics
Fall. 4 credits. 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, optical, plasma, and solid-state physics, as suggested by the students and coordinated by the instructor.

761 Kinetic Theory (also EE 681)
Fall. 3 credits. Prerequisite: EE 407, Physics 561, or permission of instructor. Offered alternate years.

2 lecs.

For description see EE 681.

762 Physics of Solid Surfaces and Interfaces
Spring. 3 or 4 credits. Lecture course primarily for graduate and qualified senior students. Primarily for beginning graduate students and seniors. Similar to MS&E 703. Offered alternate years.
An experimental approach connecting the basic physics and chemistry of electron and atomic structure with processes at surfaces and interfaces. A critical perspective on principles, with an emphasis on applications and devices from an applied-physics viewpoint. Principles involved in characterization will be discussed more than techniques and equipment. Specific concepts and phenomena will be emphasized, and only those theories and models required for their analysis will be covered. Topics include ultrahigh vacuum, surface crystallography, measurement concepts, gas-solid surfaces, solid-solid interfaces, atomic structure, surface reconstruction, electronic processes, chemical bonding, physical and chemical adsorption, nucleation and growth, particle-solid phenomena, and radiation–solid interface phenomena. At the level of *Physics at Surfaces* by Zangwill.

CHEMICAL ENGINEERING

101 Nonresident Lectures
Spring. No credit.

1 lec. G. F. Scheele and guest lecturers.

Given by lecturers invited from industry and from selected departments of the university to assist students in their transition from college to industrial life.

112 Introduction to Chemical Engineering (also Engr 112)
Fall, spring. 3 credits. Limited to freshmen.

2 lecs, 1 rec. F. Rodriguez, M. L. Shuler.

For description see Engineering Common Courses.

219 Mass and Energy Balances (also Engr 219)
Fall. 3 credits. Corequisite: physical or organic chemistry or permission of instructor.

3 lecs. 1 computing session.
A. Panagiotopoulos.

For description see Engineering Common Courses.

220 Mass and Energy Balances (also Engr 220)
Spring, summer. 3 credits. Corequisite: physical or organic chemistry and permission of instructor. Intended for transfer students who cannot take Chem E 219.

G. F. Scheele.

Self-paced audiovisual instruction in the material of Chem E 219. For description see Engineering Common Courses.

313 Chemical Engineering Thermodynamics
Fall. 4 credits. Corequisite: physical chemistry.
4 lecs, 1 computing session.
K. E. Gubbins.
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.

323 Fluid Mechanics
Fall. 3 credits. Prerequisites: Chem E 219 and engineering mathematics sequence.
3 lecs, 1 computing session. D. L. Koch.
Fundamentals of fluid mechanics. Macroscopic and microscopic balances. Applications to problems involving viscous flow.

324 Heat and Mass Transfer
Spring. 3 credits. Prerequisite: Chem E 323.
3 lecs, 1 computing session.
D. A. Hammer.
Fundamentals of heat and mass transfer. Macroscopic and microscopic balances. Applications to problems involving conduction, convection, and diffusion.

332 Analysis of Separation Processes
Spring. 4 credits. Prerequisites: Chem E 313 and 323.
3 lecs, 1 computing session.
G. F. Scheele.
Analysis of separation processes involving phase equilibria and mass transfer; some use of the digital computer. Phase equilibria; binary, multicomponent, and extractive distillation; liquid-liquid extraction; gas absorption.

390 Reaction Kinetics and Reactor Design
Spring. 3 credits. Prerequisites: Chem E 313 and 323.
3 lecs. A. B. Anton.
A study of chemical reaction kinetics and principles of reactor design for chemical processes.

432 Chemical Engineering Laboratory
Fall. 4 credits. Prerequisites: Chem E 323, 324, 332, and 390.
2 lecs, 1 lab. G. F. Scheele.
Laboratory experiments in fluid dynamics, heat and mass transfer, kinetics, other operations. Correlation and interpretation of data. Technical report writing.

462 Chemical Process Design
Spring. 4 credits. Prerequisite: Chem E 432.
P. Harriott and R. P. Merrill.
A consideration of process and economic alternatives in selected chemical processes; design and assessment.

472 Process Control
Spring. 3 credits. Prerequisites: Chem E 324, 332, and 390.
3 lecs, 1 lab. P. Clark.
Analysis of the dynamics of chemical processes and design of feedback control systems with emphasis on control of chemical reactors and separation systems.

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

564 Design of Chemical Reactors
Spring. 3 credits. Prerequisite: Chem E 390 or equivalent.
3 lecs. 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 data for gas-solid, gas-liquid, and three-phase reaction systems.

565 Design Project
Spring. 3 or 6 credits. Required for students in the M.Eng.(Chemical) program.
Staff.
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.

566 Computer-aided Process Design
Spring. 3 credits. Prerequisite: Chem E 332 or equivalent.
3 lecs. P. Clark.
An introduction to the synthesis and use of computer systems for steady-state simulation and optimization of chemical processes. Synthesis of heat exchanger networks and separation systems.

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

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

642 Polymeric Materials Laboratory
Spring. 2 or 3 credits. Prerequisite: Chem E 640.
F. Rodriguez.
Experiments in the formation, characterization, fabrication, and testing of polymers.

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

645 Advanced Concepts in Biological Engineering
Spring. 3 credits. Prerequisite: Chem E 643 or equivalent or permission of instructor.
3 lecs. D. A. Hammer.
Fundamentals of biochemical engineering science with emphasis on enzyme processing, mathematical models of cell growth, bioreactors, product recovery, bioseparations, the use of tissue culture, and genetically modified organisms.

[**646 Controlled Cultivation of Microbial Cells**
Spring (January intersession). 3 credits. Prerequisite: Microbiology 291 or equivalent. Not offered 1990–91.
Staff.
A projects course. Use of batch- and continuous-stirred jars to explore the physiology of microorganisms under conditions simulating industrial practice.]

648 Polymers in Electronics and Related Areas
Spring. 3 credits. Prerequisite: 640 or permission of instructor.
3 lecs. F. Rodriguez.
Applications of polymers as resists for microlithography, as insulators, and as conductors. Radiation effects, polymer synthesis, and surface characterization. Additional special topics may be covered.

661 Air Pollution Control
Fall. 3 credits.
3 lecs. P. Harriott.
Origin of air pollutants. Design of equipment for removal of particulate and gaseous pollutants formed in combustion and chemical processing.

673 Adsorption and Catalysis
Fall. 2 credits.
R. P. Merrill.
The physics and chemistry of adsorption on reactive surfaces and catalysis. Emphasis on the use of modern spectroscopic techniques to determine the geometric structure, electronic structure, and reaction sequences on well-defined surfaces. Discussion of several catalytic systems.

675 Synthetic Polymer Chemistry (also MS&E 671 and Chemistry 671)
Fall. 3 credits. Prerequisites: Chem 359–360 or equivalent or permission of instructor. MS&E 620 is recommended.
3 lecs. J. M. J.Frechet.
For description see Chemistry 671.

681 Dynamics of Colloidal Systems
Fall. 3 credits. Prerequisite: basic understanding of thermodynamics and fluid dynamics.
3 lecs. A. Z. Panagiotopoulos and W. L. Olbricht.
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.

711 Advanced Chemical Engineering Thermodynamics
Fall. 3 credits. Prerequisite: Chem E 313 or equivalent.
3 lecs. P. Clancy.
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.

713 Chemical Kinetics and Dynamics
Fall. 3 credits. Prerequisite: Chem E 390 or equivalent.
3 lecs. 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 biomolecular 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.

721 Thermodynamics and Phase Change Heat Transfer (also M&AE 652)
Fall. 4 credits. Prerequisite: graduate standing or permission of instructor.
C. T. Avedisian.
For description see M&AE 652.

731 Advanced Fluid Mechanics and Heat Transfer
Fall. 3 credits. Prerequisite: Chem E 323 and 324 or equivalent.
3 lecs. 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.

732 Diffusion and Mass Transfer
Spring. 2 credits. Prerequisite: Chem E 731 or equivalent.
C. Cohen.
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.

[734 Fluid Mechanics of Suspensions
Spring. 3 credits. Prerequisite: Chem E 731, M&AE 601, or equivalent. Offered alternate years. Not offered 1990–91.
D. L. Koch.
Relationship between macroscopically observed transport and rheological behavior of suspensions and composites, and underlying transport processes occurring on the particle-length scale. Methods of treating interparticle hydrodynamic interactions. Derivation of macroscopic properties using ensemble averages, renormalization, and dynamic simulations. Applications will include free suspensions of solid spheres, fibers, and bubbles; composite solids; and porous media.]

741 Selected Topics in Biochemical Engineering
Fall, spring. 1 credit (may be repeated for credit). Prerequisite: Chem E 643 or permission of instructor.
D. A. Hammer, M. L. Shuler.
Discussion of current topics and research in biochemical engineering for graduate students.

745 Physical Polymer Science I
Fall. 3 credits. Prerequisite: Chem E 711 or equivalent. Offered alternate years.
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.

751 Mathematical Methods of Chemical Engineering Analysis
Spring. 4 credits.
3 lecs. P. H. Steen.
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.

[753 Analysis of Nonlinear Engineering Systems: Stability, Bifurcation, and Continuation
Fall. 3 credits. Prerequisite: Chem E 751 or equivalent. Offered alternate years. Not offered 1990–91.
3 lecs. P. H. Steen.
Elements of bifurcation theory. Branch-following techniques. Stability of discrete and continuous systems. Application to population-dynamics, reaction-diffusion, and hydrodynamic systems using software for continuation problems.]

772 Theory of Molecular Liquids
Spring. 3 credits. Prerequisite: Chem E 711 or equivalent. Offered alternate years.
K. E. Gubbins.
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.

774 Atomistic Simulation of Materials
Spring. 3 credits. Prerequisite: Competence in FORTRAN, PASCAL, or C. Prior knowledge of statistical mechanics helpful.
2 lecs, 1 computer lab. P. Clancy.
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.

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

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

890 Thesis Research
Variable credit.
Thesis research for the M.S. degree in chemical engineering.

990 Thesis Research Variable credit.
Thesis research for the Ph.D. degree in chemical engineering.

CIVIL AND ENVIRONMENTAL ENGINEERING

General

113 Computer-aided Design in Environmental Systems (also Engr 113)
Fall. 3 credits.
2 lecs, 1 sec. C. A. Shoemaker.
For description see Engineering Common Courses.

116 Modern Structures (also Engr 116)
Fall, spring. 3 credits.
2 lecs, 1 sec. M. Sansalone.
For description see Engineering Common Courses.

241 Engineering Computation (also Engr 241)
Fall, spring. 3 credits. Prerequisites: CS 100 and Mathematics 293. Corequisite: Mathematics 294.
J. F. Abel, J. R. Stedinger.
For description see Engineering Common Courses.

304 Uncertainty Analysis in Engineering
Fall. 4 credits. Prerequisite: first-year calculus.
J. R. Stedinger.
An introduction to probability theory, statistical techniques, and uncertainty analysis, with examples drawn from civil, environmental, agricultural, and related engineering disciplines. The course covers data presentation, probability theory, commonly used probability distributions, parameter estimation, goodness-of-fit tests, confidence intervals, hypothesis testing, simple linear regression, and nonparametric statistics. Examples include structural reliability, models of vehicle arrivals, analysis of return-period calculations, and distributions describing wind speeds, floods, pollutant concentrations, and soil and material properties.

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 one or more specialized topics not covered in regular courses.

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

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

503 Professional Practice in Engineering
Spring. 3 credits. Required for and limited to students in the M.Eng.(Civil) program.
W. R. Lynn.
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.

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

Remote Sensing

411 Remote Sensing: Environmental Applications (also SCAS 461)
Spring. 3 credits. Prerequisite: permission of instructor.
2 lecs, 1 lab. W. R. Philipson.
A survey of how remote sensing is applied in various environmental disciplines. Laboratory emphasis is on using aircraft and satellite imagery for inventorying and monitoring surface features in engineering, planning, agriculture, and natural resource assessments.

610 Remote Sensing Fundamentals (also Agronomy 660)
Fall. 3 credits. Prerequisite: permission of instructor.
2 lecs, 1 lab. W. R. Philipson.
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.

[612 Physical Environment Evaluation
Fall. 3 credits. Prerequisite: permission of instructor. Not offered 1990–91.
2 lecs, 1 lab. Staff.
Physical environmental factors affecting engineering planning decisions: climate, soil and rock conditions, water sources. Evaluation methods: interpretation of meteorological, topographic, geologic, and soil maps, aerial photographs, and subsurface exploration records.]

[613 Image Analysis I: Landforms
Fall. 3 credits. Prerequisite: permission of instructor. Not offered 1990–91.
2 lecs, 1 lab. Staff.
Analysis and interpretation of aerial photographs for a broad spectrum of soil, rock, and drainage conditions. Specific fields of application are emphasized.]

[614 Image Analysis II: Physical Environments
Fall. 3 credits. Prerequisite: CEE 612 or 613. Not offered 1990–91.
2 lecs, 1 lab. Staff.
Study of physical environments using aerial photographs and other remote sensing methods. Conventional photography; spectral, space, and sequential photography; thermal and radar imageries. Arctic, tropic, arid, and humid climate regions. Project applications.]

615 Digital Image Processing
Fall. 3 credits. Prerequisites: facility with algebra (Mathematics 109) and statistics (CEE 304 or Agricultural Economics 310), or permission of instructor.
W. D. Philpot.
An introduction to digital image-processing concepts and techniques, with emphasis on techniques used in 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.

616 Digital Image Analysis
Spring. 3 credits. Prerequisites: calculus (Mathematics 192), statistics (CEE 304 or Agricultural Economics 310), and computer programming (FORTRAN or C), or permission of instructor.
W. D. Philpot.
Pattern recognition, feature extraction, and classification of digital images as used in remote-sensing applications. Both spectral and spatial patterns will be considered. Assignments will require the development of computer programs and will make use of existing image-processing software and graphics.

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

618 Special Topics—Remote Sensing
On demand. 1–6 credits.
Staff.
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.

619 Seminar in Remote Sensing (also SCAS 662)
Spring. 1 credit. S-U grades only.
W. R. Philipson.
Lectures on current developments in assessing earth resources or the environment. Each week a different topic on remote sensing or geographic information systems is presented by specialists from government, industry, Cornell, or other research or academic institutions.

710 Research—Remote Sensing
On demand. 1–6 credits.
Staff.
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.

810 Thesis—Remote Sensing
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term.
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

321 Microeconomic Analysis (also Engr 321 and Economics 313, section 5)
Fall. 4 credits. Prerequisite: one semester of calculus. A social science elective for engineering students.
R. E. Schuler.
For description see Engineering Common Courses.

322 Economic Analysis of Government (also Engr 322 and Economics 308)
Spring. 4 credits. Prerequisites: one semester of calculus, plus CEE 321 or Economics 313. A social science elective for engineering students.
R. E. Schuler.
For description see Engineering Common Courses.

323 Engineering Economics and Management (also Engr 323)
Spring. 3 credits. Primarily for juniors and seniors.
D. P. Loucks.
For description see Engineering Common Courses.

325 System Perspectives on Solid Waste Management
Fall. 3 credits. Open to juniors and seniors from all colleges who have had freshman chemistry or physics, and a calculus course.
D. W. Ditz, R. E. Schuler.
An introduction to alternative technological solutions to society's solid waste problems with the interdisciplinary perspective of how those proposals interact with a broad range of public, environmental, and economic concerns. Using engineering, economic, legal, and political professionals, an integrated systems approach to problem solving will be emphasized and will culminate in a semester project in solid waste management planning that requires written and oral presentations by small groups. Field trips to operating facilities.

528 Interactive Modeling with Microcomputer Graphics
Spring. 3 credits. Prerequisite: Engr 241 or Engr 222, and permission of instructor.
D. P. Loucks.
Principles of interactive modeling and its application to the design and management of civil, environmental, and water-resources engineering systems. Topics will include tablet and video digitizing, image processing (including editing and overlaying pictures and maps), contouring, opaque and transparent coloring, generating 2-D and 3-D colored graphs, and developing pre- and postprocessors to permit the interactive use of various models for synthesizing designs and operating policies and for predicting system performance. Microcomputers with high-quality color-graphics capabilities will be available together with numerous interactive graphics subroutines for use in C or FORTRAN programs.

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

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

621 Water-Resources Systems II
Spring. 3 credits. Prerequisites: CEE 304 and 620 or permission of instructor.
J. R. Stedinger, D. P. Loucks.
Advanced topics in the development and use of optimization and simulation models for water-resources planning. Stochastic hydrologic modeling and stochastic river-basin and reservoir models. Incorporates material in CEE 622.

622 Stochastic Hydrologic Modeling
On demand. 2–3 credits. Prerequisite: OR&IE 370 or CEE 304.
J. R. Stedinger.
Develops statistical techniques used to analyze and model stochastic processes. Examination of Box-Jenkins, fractional-Brownian noise, and other single- and multiple-site stream-flow models; review of flood-frequency estimation issues; analysis of simulation output; parameter estimation and Bayesian inference.

623 Water Quality Systems Analysis
Spring. 3 credits. Prerequisites: Math 294 and optimization (CEE 323, Ag En 475, or OR&IE 320/520).
C. A. Shoemaker.
Applications of optimization and simulation methods to the design and operation of facilities for managing the quality of surface- and groundwater. Applications include location of wastewater and hazardous-waste facilities, restoration of dissolved oxygen levels in rivers, and reclamation of contaminated aquifers. Optimization techniques include separable convex (linear) programming, integer programming, and nonlinear programming.

[626 Modeling Managed Ecosystems
Fall, on demand. 3 credits. Prerequisites: Mathematics 294, statistics, and population ecology. Not offered 1990–91.
C. A. Shoemaker.
The use of optimization and statistical estimation procedures to develop strategies for managing populations and ecosystems. Primary focus will be on pest management, poikilotherm populations, and mitigation of potential pollution from pesticides.]

721 Environmental and Water Resources Systems Analysis Design Project
On demand. Variable credit. Prerequisite: permission of instructor. May extend over two semesters.
Staff.
Design or feasibility study of environmental or water resources sytems, supervised and assisted by one or more faculty advisers; individual or group participation. Final report required.

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

728 Environmental and Water Resources Systems Analysis Colloquium
Fall, spring. 1 credit.
Staff.
Lectures in various topics related to environmental or water resources systems planning and analysis.

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

Fluid Mechanics and Hydrology

331 Fluid Mechanics
Fall. 4 credits. Prerequisite: Engr 203 (may be taken concurrently).
3 lecs, 1 rec, evening exams. P. L.-F. Liu.
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.

332 Hydraulic Engineering
Spring. 4 credits. Prerequisite: CEE 331.
2 lecs, 1 lab, field trip. G. H. Jirka.
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.

430 Descriptive Hydrology
On demand. 2 credits. Intended for non-engineering majors. Prerequisite: permission of instructor.
W. H. Brutsaert.
Introduction to hydrology as a description of the hydrologic cycle and the role of water in the natural environment. Topics include precipitation, infiltration, evaporation, groundwater, surface runoff, floods, and droughts.

431 Geohydrology (also ABEN 471 and Geol 445)
Fall. 3 credits. Prerequisite: permission of instructor.
G. H. Jirka with J.-Y. Parlange and T. S. Steenhuis (in ABEN) and A. L. Bloom and L. Cathles (in Geol).
An intermediate course in aquifer geology, groundwater flow, and related design factors. Includes description and properties of natural aquifers, groundwater hydraulics, soil water, and solute transport.

630 Advanced Fluid Mechanics
Fall. 3 credits. Prerequisite: CEE 331. Offered alternate years.
3 lecs. J. A. Liggett.
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.

631 Flow and Contaminant Transport Modeling in Groundwater
Spring. 3 credits. Prerequisites: Mathematics 294 or equivalent, Engr 241 or experience in numerical methods and programming, and elementary fluid mechanics.
J. A. Liggett.
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.

[632 Analytical Hydrology
Spring. 3 credits. Prerequisite: CEE 331. Not offered 1990–91.
W. H. Brutsaert.
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.]

[633 Flow in Porous Media and Groundwater
Spring. 3 credits. Prerequisite: CEE 331. Not offered 1990–91.
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.]

[634 Engineering Micrometeorology
Fall. 3 credits. Prerequisite: CEE 331 or permission of instructor. Not offered 1990–91.
3 lecs. 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.]

635 Coastal Engineering I
Spring. 3 credits. Prerequisite: CEE 331.
3 lecs. P. L.-F. Liu.
Linear wave theory, wave generation by wind, analysis of fluid forces on floating and fixed coastal structures and modification of waves and currents by these structures, coastal processes, and coastal sediment motion.

636 Environmental Fluid Mechanics
Spring. 3 credits. Prerequisite: CEE 655. Offered alternate years.
G. H. Jirka.
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.

637 Project—Hydraulics
On demand. Variable credit.
Hours to be arranged. Staff.
The student may elect a design problem or undertake the design and construction of special equipment in the fields of fluid mechanics, hydraulic engineering, or hydrology.

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

639 Special Topics in Hydraulics
On demand. Variable credit.
Staff.
Special topics in fluid mechanics, hydraulic engineering, or hydrology.

[730 Coastal Engineering II
Spring. 3 credits. Prerequisite: CEE 635. Not offered 1990–91.
3 lecs. P. L.-F. Liu.
Review of linear and nonlinear theories for ocean waves, applicability of different wave theories to engineering problems, wave-energy transmission, tsunamis, behavior of submerged and floating bodies, harbor agitations, ship waves.]

[732 Unsteady Hydraulics
Spring. 3 credits. Prerequisite: CEE 332 or permission of instructor. Offered alternate years. Not offered 1990–91.
J. A. Liggett.
The physical and mathematical basis for unsteady processes in hydraulic engineering, especially unsteady open-channel flow. Water hammer, unsteady sediment transport, long waves on large bodies of water, circulation. Numerical methods of solution.]

734 Experimental Methods in Hydraulics
On demand. 2 credits. Prerequisite: CEE 331.
G. H. Jirka.
Methods used in planning and conducting laboratory and field experiments in hydraulics and fluid mechanics. Dynamic similarity, modeling laws, and applications. General operating principles and performance characteristics of measurement instruments. Specific devices for measurement of fluid properties, pressure, and flow. Data acquisition, processing, and signal analysis. Laboratory demonstrations.

735 Research in Hydraulics
On demand. Variable credit.
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.

Geotechnical Engineering

341 Introduction to Geotechnical Engineering
Spring. 4 credits.
3 lecs, 1 lab-tutorial. Staff.
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.

640 Foundation Engineering
Fall. 3 credits. Prerequisite: CEE 341.
3 lecs, optional tutorial. Staff.
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.

641 Retaining Structures and Slopes
Spring. 3 credits. Prerequisite: CEE 341.
3 lecs, optional tutorial. Staff.
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.

642 Highway Engineering (also ABEN 491)
Spring. 3 credits. Prerequisites: junior standing in engineering, fluid mechanics, and soil mechanics (may be taken concurrently).
2 lecs, 1 lab. L. H. Irwin.
For description see ABEN 491.

643 Pavement Engineering (also ABEN 692)
Fall. 4 credits. Limited to engineering seniors and graduate students. Prerequisites: CEE 341 and 642. Offered alternate years.
3 lecs, 1 lab. L. H. Irwin.
For description see ABEN 692.

647 Design Project in Geotechnical Engineering
On demand. 1–6 credits.
Students may elect to undertake a design project in geotechnical engineering. The work is supervised by a professor in the subject area.

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

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

740 Engineering Behavior of Soils
Fall. 4 credits. Prerequisite: CEE 341.
3 lecs, 1 lab. Staff.
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. Weekly laboratory sessions include in-situ field testing, simple index tests, and complete laboratory characterization of important soil properties.

741 Rock Engineering
Fall. 3 credits. Prerequisite: CEE 341 or permission of instructor. Recommended: introductory geology.
2 lecs, 1 lab. 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.

[744 Advanced Foundation Engineering
Spring. 2 credits. Prerequisite: CEE 640. Not offered 1990–91.
2 lecs. Staff.
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, pile-driving dynamics, foundations for special structures.]

745 Soil Dynamics
Spring. 4 credits. Prerequisite: permission of instructor.
3 lecs, 1 lab. Staff.
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.

746 Embankment Dam Engineering
Spring. 2 credits. Prerequisites: CEE 641 and 741, or permission of instructor.
2 lecs. Staff.
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.

[747 Case Studies in Geotechnical Engineering
Spring. 3 credits. Prerequisites: CEE 641 and 741. Not offered 1990–91.
Staff.
Study of case histories in geotechnical engineering. Critical evaluation of successful and unsuccessful projects. Oral presentations and engineering report evaluation of each case.]

[748 Tunnel Engineering
Spring. 2 credits. Prerequisites: CEE 641 and 741. Not offered 1990–91.
2 lecs. Staff.
Principles of analysis and design for earth and rock tunnels. Materials, construction methods, stability and support systems, deformations, and performance monitoring.]

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.

Environmental Engineering

351 Environmental Quality Engineering
Spring. 3 credits.
3 lecs. L. W. Lion.
Introduction to engineering aspects of environmental quality control. Quality parameters, criteria, and standards for water and wastewater. Emphasis on water-quality control concepts, theory, and methods. Elementary analysis pertaining to the modeling of pollutant reactions in natural systems, and introduction to design of unit processes for water and wastewater treatment.

352 Water Supply Engineering
Fall. 3 credits. Prerequisite: CEE 351 or permission of instructor.
3 lecs. R. I. Dick.
Analysis of contemporary threats to human health by public water supply systems. Criteria and standards for potable-water quality. Water-quality control theory. Design of facilities for obtaining, treating, storing, and distributing water.

651 Microbiology of Water and Wastewater
Fall. 2 credits. Prerequisite: one semester of college chemistry.
2 lecs. 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.

653 Chemistry of Water and Wastewater
Fall. 3 credits. Prerequisite: one semester of college chemistry or permission of instructor.
3 lec-recs. 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.

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

655 Pollutant Transport and Transformation in the Environment
Fall. 3 credits. Prerequisite: CEE 331.
J. J. Bisogni, G. H. Jirka.
An introduction to the physical transport and chemical and biochemical transformation processes that govern the fate and distribution of pollutants in the environment. Advective and diffusive mass transport, turbulent diffusion and shear-flow dispersion in water or atmosphere, dispersion in groundwater flow, homogeneous and heterogeneous chemical reactions and their effects on transport phenomena, air-water-soil interface transfer processes. Emphasis on physical mechanisms, with some applications to surface water, groundwater, and atmospheric transport and quality models.

658 Sludge Treatment, Utilization, and Disposal
Spring. 3 credits. Prerequisite: CEE 351 or permission of instructor. May not be offered 1990–91.
3 lecs. R. I. Dick.
Analysis of the quantity and quality of residues produced from municipal and industrial water-supply and pollution-control facilities as a function of process design and operational variables; alternatives for reclaiming or disposing of hazardous and nonhazardous residues with assessment of potential environmental impacts; fundamental factors influencing performance of treatment processes for altering sludge properties prior to reuse or ultimate disposal; and considerations in selection and integration of sludge-management processes to approach optimal design.

659 Environmental Quality Engineering Seminar
Spring. 1 credit. Intended for all graduate students in environmental engineering; open to others with permission of instructor.
R. I. Dick.
Presentation and discussion of current research and design projects in environmental engineering.

755 Environmental Engineering Processes I
Fall. 3 credits. Prerequisite: Previous or concurrent enrollment in CEE 653 or permission of instructor.
3 lecs. J. J. Bisogni.
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.

756 Environmental Engineering Processes II
Spring. 3 credits. Prerequisites: CEE 651 and 755, or permission of instructor.
3 lecs. 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.

757 Environmental Engineering Processes Laboratory I
Fall. 1 credit. Prerequisite: concurrent enrollment in CEE 653 and CEE 755.
1 lab. 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.

758 Environmental Engineering Processes Laboratory II
Spring. 1 credit. Prerequisite: CEE 651 and concurrent enrollment in CEE 756.
1 lab. J. M. Gossett.
Laboratory studies of microbiological phenomena and environmental engineering processes. Topics include microscopy; biochemical and chemical oxygen demand; enzymatic assays for microbial inhibition; disinfection; aerobic and anaerobic biological treatability studies; enumeration of bacteria.

759 Special Topics in Environmental Engineering
On demand. Variable credit.
Hours to be arranged. Staff.
Supervised study in special topics not covered in formal courses.

851 Thesis—Environmental Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term.
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

361 Introduction to Transportation Engineering
Spring. 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. Vehicle and system technology; traffic flow and control; supply-demand interactions; system planning, design, and management. Institutional and energy issues; environmental impact.

660 Transportation Planning and Policy
Fall. 3 credits. Prerequisite: permission of instructor.
A. H. Meyburg.
Public-sector planning and decision making for transportation. Problems of urban transportation and their implications. A systems-analysis approach to formulation of transportation policy at the local, regional, state, and federal levels. Consideration of urban-transportation planning models.

664 Transportation Systems Design
Spring. 3 credits. Prerequisite: CEE 361.
Staff.
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.

761 Transportation Design Project
On demand. Variable credit.
Staff.
Design or feasibility study of transportation systems, supervised by one or more faculty advisers. Individual or group participation.

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

764 Special Topics in Transportation
On demand. Variable credit.
Staff.
Advanced subject matter not covered in depth in other regular courses.

Structural Engineering

371 Structural Behavior
Fall. 4 credits. Prerequisite: Engr 202.
3 lecs, one 2-hour lab, evening exams.
P. Gergely.
Fundamental concepts of structural engineering. Behavior, analysis, and design. Loads, structural form, statically determinate analysis, approximate analysis of indeterminate systems. Use of interactive graphical analysis programs. Fundamentals of behavior and design of steel and concrete members.

372 Structural Analysis
Spring. 4 credits. Prerequisite: CEE 371.
3 lecs, one 2-hour lab, evening exams.
Staff.
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. Role and limitations of analysis in design. The art of structural modeling for analysis and design.

373 Design of Concrete Structures
Fall. 4 credits. Prerequisites: CEE 372 or permission of instructor. Prerequisites or corequisites: CEE 376 and Engr 261.
2 lecs, one 2-hour lab, design project.
A. H. Nilson.
Behavior and design of reinforced concrete, prestressed concrete, and composite structures.

374 Design of Steel Structures
Spring. 4 credits. Prerequisite: CEE 372 or permission of instructor. Prerequisites or corequisites: CEE 376 and Engr 261.
3 lecs, one 2-hour sec, evening exams, design project. G. G. Deierlein, T. Peköz.
Behavior and design of steel members, connections, and structures. Discussion of structural systems for buildings and bridges.

376 Civil Engineering Materials
Fall. 3 credits.
2 lecs, 1 lab. K. C. Hover.
Engineering properties of concrete, steel, wood, and other structural materials. Design characteristics and significance of test results of materials used in engineering works. Developing QA/QC programs and writing specifications. Extensive laboratory testing and report writing.

671 Random Vibration
Fall. 3 credits. Prerequisites: M&AE 326, CEE 779, and OR&IE 260; or equivalent and permission of instructor. Offered alternate years.
M. D. Grigoriu.
Review of random-process theory, simulation, and first-passage time. Linear random vibration: second-moment response descriptors and applications from fatigue; seismic analysis; and response to wind, wave, and other non-Gaussian load processes. Nonlinear random vibration: equivalent linearization, perturbation techniques, Fokker-Planck and Kolmogorov equations, Itô calculus, and applications from chaotic vibration, fatigue, seismic analysis, and parametrically excited systems.

672 Fundamentals of Structural Mechanics
Fall. 3 credits. Prerequisite or corequisite: CEE 373.
M. D. Grigoriu.
Theory of elasticity, energy principles, plate flexure, failure theories for structural design, beams on elastic foundation, finite-difference method, plate theory, energy principles, introduction to finite-element method.

673 Advanced Structural Analysis
Fall. 3 credits. Prerequisites: CEE 372 and computer programming.
Evening exams, programming project.
Staff.
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.

674 Structural Model Analysis and Experimental Methods
Spring. 3 credits.
2 lecs, 1 lab. R. N. White.
Experimental behavior of structures. Dimensional analysis and similitude. Model materials, fabrication, loading, instrumentation techniques, and use of models in design. Experimental stress analysis. Laboratory exercises and project.

675 Concrete Materials and Construction
Spring. 3 credits. Prerequisite: CEE 376 or equivalent.
2 lecs, 1 lab. 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. Lab assignments.

678 Low-Cost Housing Primarily for Developing Countries (also Architecture 614)
Fall. 3 credits. May not be offered 1990–91.
2 lecs, conferences. H. Richardson.
A broad, multidisciplinary approach covering technology, architecture, planning, sociology, economy, and cultural aspects. Students work in teams on a term project, applying their own discipline while being introduced to the problems and approaches of other disciplines. For example, engineering students investigate the technological aspects of the subject but also learn about other matters that influence technological decisions, such as cultural and economic factors.

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

[770 Engineering Fracture Mechanics
Fall. 3 credits. Prerequisite: CEE 772 or permission of instructor. Offered alternate years. Not offered 1990–91.
2 lecs, 1 lab. 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.]

772 Finite-Element Analysis
Spring. 3 credits. Prerequisites: CEE 672 and 673, or permission of instructor.
Staff.
Conceptual, theoretical, and practical bases for finite-element analysis in structural mechanics and other disciplines. Development and evaluation of formulations for one-, two-, and three-dimensional elements. Introduction to boundary-element analysis. Interactive computer graphics for finite- and boundary-element analysis.

773 Structural Reliability
Spring. 3 credits.
M. D. Grigoriu.
Review of probability theory, practical measures for structural reliability, second-moment reliability indices, probability models for strength and loads, probability-based design codes, reliability of structural systems, imperfection-sensitive structures, fatigue, stochastic finite-element techniques, elementary concepts of probabilistic fracture mechanics.

774 Prestressed Concrete Structures
Spring. 3 credits. Prerequisites: CEE 373 and 376 or equivalent. Recommended: CEE 775.
3 lecs. R. N. White.
Behavior, analysis, design of pretensioned and posttensioned prestressed concrete structures. Flexure, shear, bond, anchorage zone design, cracking, losses. Partial prestressing. Strength, serviceability, structural efficiency of beams, slabs, tension members, frameworks, parking garages, and bridges.

775 Advanced Reinforced Concrete
Fall. 3 credits. Prerequisites: CEE 373 and 376 or equivalent.
3 lecs. A. H. Nilson.
General flexural analysis, deflection analysis, columns with uniaxial and biaxial bending, beam-supported slabs, flat-plate slabs, composite steel-deck slabs, ground-supported slabs, yield-line theory, limit-state analysis, footings, retaining walls, deep beams, tall buildings, and seismic design.

[776 Advanced Design of Metal Structures
Fall. 3 credits. Prerequisite: CEE 374 or equivalent. Not offered 1990–91.
T. Peköz.
Preliminary design of structural systems. Design of members and connections. Behavior and computer-aided design of building frames. Design of composite members.]

777 Advanced Behavior of Metal Structures
Spring. 3 credits. Prerequisite: CEE 374 or equivalent.
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.

778 Shell Theory and Design
Fall. 2–3 credits. Offered alternate years.
P. Gergely.
Fundamentals of practical shell theory. Differential geometry of surfaces; membrane and bending theory of shells; analysis and design of cylindrical shells, polygonal domes, and paraboloids.

779 Structural Dynamics and Earthquake Engineering
Spring. 3 credits.
P. Gergely.
Modal analysis, numerical methods, and frequency-domain analysis. Introduction to earthquake-resistant design.

780 Advanced Concrete Material Science
Fall. 3 credits. Prerequisites: CEE 376 or equivalent and CEE 675.
K. C. Hover.
Advanced study of the chemistry, physics, and microstructure of cement and concrete. Investigation of cement manufacture and chemistry, hydration reactions and effect of admixtures. Study of microstructure with scanning electron microscopy, and porosimetry. Engineering properties and behavior include failure mechanisms and elastic and viscoelastic behavior. Durability. Student presentations.

782 Advanced Topics in Finite-Element Analysis
Fall. 3 credits. Prerequisite: CEE 772. Offered alternate years.
J. F. Abel, A. R. Ingraffea.
Lectures and colloquia on selected advanced topics and research in progress, including dynamics, nonlinear analysis, shells, fracture mechanics, fluid dynamics, and computer graphics.

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

784 Design Project in Structural Engineering
Fall, spring. Variable credit.
Students may elect to undertake a design project in structural engineering. The work is supervised by a professor in this subject area.

785 Research in Structural Engineering
On demand. Variable credit.
Hours to be arranged. Staff.
Pursuit of a branch of structural engineering beyond what is covered in regular courses. Theoretical or experimental investigation of suitable problems.

786 Special Topics in Structural Engineering
On demand. Variable credit.
Hours to be arranged. Staff.
Individually supervised study or independent design or research in specialized topics not covered in regular courses.

880 Thesis—Structural Engineering
Fall, spring. 1–12 credits. Students must register for credit with the professor at the start of each term. Geotechnical engineering: section 01; structural engineering: section 02.
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

590 Engineering Management Practice
Fall. 3 credits. Prerequisite: permission of instructor.
K. C. Hover.
An introduction to the work and skills of management. Planning, organizing, communicating, controlling, and correcting will be covered in combination of lectures, readings, outside assignments, in-class role-playing exercises, and talks by visiting speakers.

591 Engineering Management Project
Fall. 3 credits. Prerequisite: permission of instructor.
K. C. Hover, M. A. Turnquist.
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.

592 Engineering Management Project
Spring. 3 credits. Prerequisite: permission of instructor.
K. C. Hover, M. A. Turnquist.
A continuation of CEE 591.

593 Engineering Management Methods I
Fall. 3 credits. Prerequisite: permission of instructor.
M. A. Turnquist.
Engineering management methods with an emphasis on modern interactive-software tools. Case studies are used extensively to illustrate the application of these methods to engineering management problems. Methods covered include spreadsheets, database management, statistical analysis, project scheduling, optimization, and quality control.

594 Engineering Management Methods II
Spring. 3 credits. Prerequisite: permission of instructor.
M. A. Turnquist.
An extension of CEE 593. Modeling of stochastic systems using spreadsheets, distributed databases, simulation of complex systems, and the use of expert systems in engineering management. Extensive use is made of projects and case studies to illustrate the application of these methods.

595 Construction Planning and Operations
Fall. 3 credits. Prerequisite: permission of instructor.
3 lecs. K. C. Hover.
A course on the fundamentals of construction planning: organization of the worksite, construction planning, scheduling, and cost estimating, bidding design of falsework and shoring systems, construction loadings, materials handling for construction, optimization of construction processes, applications of computer methods.

596 Building Systems Integration
Spring. 3 credits. Prerequisite: permission of instructor.
3 lecs. Staff.
Emphasizes the engineering design and construction process as a total systems problem: overall structural planning and the sequence of assembly, impact of assembly details on construction procedures, review of designs for constructability, integration of engineering services, introduction to value engineering, construction documents, and contract administration.

597 Risk Analysis and Management
Spring. 3 credits. Prerequisite: CEE 304 or OR&IE 270 or equivalent.
2 lecs, 1 sec. M. A. Turnquist, J. R. Stedinger.
The analysis and management of risks in technological systems, including energy production, waste disposal, engineering construction, and transportation. Probability models of failure, exposure, and consequences. Public-sector decision making and regulation of risks.

598 Decision Making in Engineering Systems
Spring. 3 credits. Prerequisite: permission of instructor.
3 lecs. Staff.
An examination of the decision-making behavior of managers and users of engineering systems. Such behavior will be addressed from various perspectives, including economic theories of choice, psychological theories of perception and choice, and consumer theories from marketing research.

COMPUTER SCIENCE

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

100 Introduction to Computer Programming (also Engr 100)
Fall, spring, summer. 4 credits. Students who plan to take CS 101 or 102 and also 100 must take 101 or 102 first.
2 lecs, 1 rec (optional), 3 evening exams.
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 Pascal. The course does not presume previous programming experience. An introduction to numerical computing is included, although no college-level mathematics is presumed. Programming assignments are tested and run on interactive, stand-alone microcomputers.

101 The Computer Age (also Engr 101)
Fall, summer. 3 credits. Credit is granted for both CS 100 and 101 only if 101 is taken first.
An introduction to computer science and programming for students in nontechnical areas. The aims of the course are to acquaint the student with the major ideas in computer science and to develop an appreciation of algorithmic thinking. Topics include the history of computation; microtechnology; the retrieval and transmission of information; scientific computing; computer graphics, art, and music; robotics, natural-language processing, and machine intelligence. Students

become acquainted with the notion of an algorithm by writing several programs in Pascal or LISP and testing them on microcomputers. The amount of programming is about half that taught in CS 100. Each student writes a term paper on some aspect of computing.

102 Introduction to Microcomputer Applications (also Ag Engr 102)
Fall. 3 credits. Each lab section limited to 16 students. Not open to engineering students or students who have taken any prior computer courses at Cornell. Students in statutory colleges must enroll in Ag Engr 102.
2 lecs, 1 lab, 2 evening exams.
An introduction to the use of application packages on microcomputers. An attempt will be made to assess and demonstrate the capability and limitations of the current generation of personal computers through software for word processing, spreadsheets, databases, and other applications. The course will involve very little programming with high-level languages.

107 An Introduction to SCHEME
Spring. 1 credit. Prerequisite: Introductory course in PASCAL, or equivalent programming experience.
1 lec.
An accelerated introduction to SCHEME, a dialect of LISP. Recommended for students who intend to pursue the computer science major. Taught in the first four weeks of the semester.

172 An Introduction to Artificial Intelligence (also Engr 172)
Spring. 4 credits. Prerequisites: CS 100 or CS 101; and precalculus-level mathematics.
3 lecs, 2 evening exams.
For description see Engineering Common Courses.

211 Computers and Programming (also Engr 211)
Fall, spring, summer. 3 credits. Credit will not be granted for both CS 211 and 212. Prerequisite: CS 100 or equivalent programming experience.
2 lecs, 1 rec, 2 evening exams.
Intermediate programming in a high-level language and introduction to computer science. Topics include program development, proofs of program correctness, program structure, recursion, abstract data types, data structures, and analysis of algorithms. Pascal is the principal programming language.

212 Modes of Algorithmic Expression
Fall. 4 credits. Credit will not be granted for both CS 211 and 212. Prerequisite: CS 100 or equivalent programming experience.
2 lecs, 2 recs, 2 evening exams.
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. Programs are written in Scheme, a dialect of LISP.

CS 212 emphasizes a varied collection of advanced programming concepts and techniques available in a modern functional programming language. In contrast, CS 211 focuses on perfecting programming skills in a conventional imperative programming language. Corrective transfers between CS 211 and 212 (in either direction) are encouraged during the first few weeks of instruction.

222 Introduction to Scientific Computation (also Engr 222)
Spring. 3 credits. Prerequisites: CS 100 and Mathematics 112, 122, or 192.
2 lecs, 1 rec, 2 evening exams.
An introduction to elementary numerical analysis and scientific computation. Students write FORTRAN programs and use high-quality numerical software packages to solve representative problems. Emphasis is on efficient, reliable, and stable methods for the basic problems of computational mathematics. Special topics include supercomputing and parallel computation.

280 Discrete Structures
Fall, spring. 4 credits. Prerequisite: CS 211, 212 or permission of instructor.
3 lecs.
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.

314 Introduction to Computer Systems and Organization
Fall, spring, summer. 4 credits. Prerequisite: CS 211 or equivalent.
2 lecs, 1 sec, 2 evening exams.
Introduction to the logical structure of digital computers. Topics include representation of information, machine-assembly language, the input-output channel, hierarchical storage systems, and microprogramming.

381 Introduction to Theory of Computing
Fall. 4 credits. Prerequisite: CS 280 or permission of instructor.
3 lecs.
An introduction to modern theory of computing: automata theory, formal languages, and effective computability.

400 The Science of Programming
Spring. 4 credits. Prerequisite: CS 280 or equivalent. Not offered every year.
3 lecs. D. Gries.
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.

405 Science and the Computer
Fall. 4 credits. Prerequisites: Juniors and seniors only, some scientific computing experience recommended. Not offered every year.
2 lecs, 2 evening exams.
How computers affect the conduct of science. Simulation and the scientific method, visualization and the discovery process, notation and the expression of scientific ideas, quantification in the social and biological sciences, the gap between science and the public. Strong writing component.

410 Data Structures
Fall, spring, summer. 4 credits. Prerequisite: CS 280 or permission of instructor.
2 lecs, 2 evening exams.
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.

411 Programming Languages and Logics
Spring. 4 credits. Prerequisite: CS 410 or permission of instructor. Not offered every year.
2 lecs.
A study of major programming paradigms. Basic l-calculus. Functional programming. Programming in ML. Typed l-calculi. Polymorphism, type systems. Object-oriented programming and inheritance. Logic programming. Introduction to formal semantics.

412 Introduction to Compilers and Translators
Spring. 4 credits. Prerequisites: CS 314, 381, 410. Not offered every year.
3 lecs.
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.

414 Systems Programming and Operating Systems
Fall. 3 credits. Prerequisite: CS 314 or permission of instructor.
2 lecs, 2 evening exams.
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.

415 Practicum in Operating Systems
Fall. 2 credits. Prerequisite: CS 410. Corequisite: CS 414.
1 lec.
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.

417 Computer Graphics (also Architecture 374)
Fall. 3 credits. Prerequisite: CS 211 or 212. Not offered every year.
2 lecs, 1 lab.
An introduction to the principles of interactive computer graphics, including input techniques, display devices, display files, interactive graphic techniques, two- and three-dimensional computer graphics, perspective transformations, hidden-line and hidden-surface algorithms, parametric surfaces, light reflection models, and realistic image synthesis.

418 Practicum in Computer Graphics (also Architecture 375)
Fall. 2 credits. Prerequisite: CS 211 or 212. Recommended: CS 314. Corequisite: CS 417. Not offered every year.
1 lab.
Two or three programming assignments dealing with sophisticated interactive vector graphics programs on calligraphic displays and solid image generation or raster graphics displays.

421 Numerical Solution of Algebraic Equations
Fall. 4 credits. Prerequisites: Mathematics 222 or 294, one additional mathematics course numbered 300 or above, and knowledge of FORTRAN at the CS 222 level.
3 lecs.
Modern algorithms for systems of linear equations, systems of nonlinear equations, and multidimensional optimization. Some discussion of methods that are suitable for parallel computation.

432 Introduction to Database Systems
Spring. 3 credits. Prerequisites: Either CS 211or 212, and 410, or permission of instructor. Recommended: CS 314.
2 lecs, 1 rec.
Introduction to modern database management systems. Concepts in data modeling and query processing. Database models and query languages. Storage structures and access methods. Concurrency control.

433 Practicum in Database Systems
Spring. 2 credits. Corequisite: CS 432.
1 lab.
Issues related to the design and implementation of database-management systems will be addressed. Students will implement a simplified relational database system, including a file-access method and query-processing algorithms.

472 Foundations of Artificial Intelligence
Fall. 3 credits. Prerequisites: CS 107 or CS 212, CS 280 and CS 410. Open to juniors, seniors, and graduate students.
2 lecs, 1 sec.
An introduction to the major subareas and current research directions in artificial intelligence. Topics include knowledge representation, search, problem-solving, natural-language processing, logic and deduction, planning, and machine learning.

473 Practicum in Artificial Intelligence
Spring. 2 credits. Prerequisite: CS 107 or CS 212, CS 280 and CS 410. Corequisite: CS 472.
1 lab.
Project portion of CS 472. Topics include Common LISP programming, representation systems, deductive retrieval, databases and frame languages, and truth-maintenance-system implementations.

481 Introduction to Theory of Computing
Spring. 4 credits. Prerequisite: CS 280 or permission of instructor. Credit will not be granted for both CS 381 and CS 481. Corrective transfers between CS 481 and CS 381 (in either direction) are encouraged during the first few weeks of instruction.
3 lecs.
A faster-moving and deeper version of CS 381.

482 (382) Introduction to Analysis of Algorithms
Spring. 4 credits. Prerequisites: CS 410 and either 381 or 481, or permission of instructor.
3 lecs.
Techniques used in the creation and analysis of algorithms. Combinatorial algorithms, computational complexity, NP-completeness, and intractable problems.

486 Applied Logic (also Mathematics 486)
Fall or summer. 4 credits. Prerequisites: Mathematics 222 or 294, CS 100, and some additional course in mathematics or theoretical computer science.
2 lecs, 1 lab to be arranged.
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 l-calculus reduction strategies. Topics in Prolog, LISP, ML, or Nuprl. Applications to expert systems and program verification.

490 Independent Reading and Research
Fall, spring. 1–4 credits.
Independent reading and research for undergraduates.

600 Computer Science and Programming
Fall. 1 credit. Prerequisite: graduate standing in computer science or permission of instructor.
1 lec.
An introduction to practical, modern ideas in programming methodology. Covers style and organization of programs, basic techniques for presenting proofs of correctness of programs, and the use of a "calculus" for the derivation of programs.

601 Introduction to Programming Logics
Spring. 1 credit. Prerequisite: graduate standing in computer science or permission of instructor.
1 lec.
Exploration of logics for reasoning about programs, with special emphasis on data types and type theory. Comparison with domain theory and logics of computable functions. The Cornell proof development system Nuprl may be used.

611 Advanced Programming Languages
Fall. 4 credits. Prerequisites: CS 410 and 381 or 481, or permission of instructor.
3 lecs.
A survey of programming paradigms; functional, imperative, and logic programming. The untyped lambda-calculus. The typed lambda-calculus, type systems, polymorphism, type inference. Formal semantics of programming languages. Elements of domain theory.

612 Compiler Design for High-Performance Architectures
Spring. 4 credits. Prerequisites: CS 314, 410, and 412, or permission of instructor.
3 lecs.
Compiler design techniques for sequential and parallel machines. Principles of optimizing compilers: dataflow analysis, optimizing transformations, code generation. Code generation for pipelined computers: code reorganization to minimize interlock. Principles of vectorization: dependency analysis, solving Diophantine equations, transformations to enhance vector content in programs. Code generation for VLIW machines: trace scheduling. Compiling functional and logic programming languages for dataflow architectures.

613 Concurrent Programming
Spring. 4 credits. Prerequisites: CS 414 and 600, or permission of instructor.
3 lecs.
Advanced techniques in, and models of, concurrent systems. Synchronization of concurrent processes; parallel programming languages; deadlock; verification.

614 Advanced Systems
Spring. 4 credits. Prerequisite: CS 414 or permission of instructor.
2 lecs.
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.

[615 Machine Organization
Spring. 4 credits. Prerequisite: CS 314 or permission of instructor. Not offered every year.
3 lecs.]

616 RISC Microprocessor Design
Spring. 4 credits. Prerequisite: permission of instructor. Not offered every year.
2 lecs.
This project course involves design and testing of a pipelined reduced-instruction set processor. Typically, about ten students participate in the project and are assigned the design of different components of the processor, such as the ALU or register file.

621 Matrix Computations
Fall. 4 credits. Prerequisites: Mathematics 411 and 431, or permission of instructor.
3 lecs.
Numerical matrix algorithms. Stable and efficient methods for solving systems of linear equations: Gaussian elimination, Cholesky decomposition, bounded and structured systems, the QR factorization, and least-squares methods. The symmetric and unsymmetric eigenvalue problems and related computational problems. The singular value decomposition.

622 Numerical Optimization and Nonlinear Algebraic Equations
Spring. 4 credits. Prerequisite: CS 621.
3 lecs.
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.

632 Database Systems
Fall. 4 credits. Prerequisites: CS 410 and 432, or permission of instructor.
2 lecs.
Discussion of data models and the implementation of database systems, with an emphasis on current areas of research. Topics include the relational model, data-dependency theory, semantic modeling, query optimization, transaction management, and advanced issues in distributed databases.

635 Automatic Text Processing and Information Retrieval
Spring. 4 credits. Prerequisite: CS 410 or permission of instructor.
2 lecs.
Modern methods for natural language text processing. Topics include text analysis, storage and retrieval, automatic spelling aids, text compression and encryption, language understanding systems, automatic abstracting, and text generation and translation.

643 Design and Analysis of Computer Networks
Fall. 4 credits. Prerequisite: CS 414 or permission of instructor. Not offered every year.
2 lecs.
A course in computer networks and layered protocols. The following topics are presented: network topology design; data transmission within the physical layer; data-link sliding-window protocols; network layer in point-to-point long-haul networks, satellite and packet radio networks and local networks; transport and session layer protocols; internetworking. Selected topics from distributed computing will also be discussed.

655 Mathematical Foundations of Computer Modeling and Simulation (also Mathematics 655)
Fall. 4 credits. Prerequisites: Mathematics 431 and 432, or the equivalent in both content and level of mathematical sophistication, or permission of instructor. Not offered every year.
3 lecs.
This course has two parts, one purely mathematical and the other emphasizing applications. The first part is intended to introduce students to theoretical tools that are relevant to the study of robotics, solid modeling, and simulation. These tools will be drawn from the areas of real and complex algebraic geometry, topology, differential geometry, and differential equations. The second part of the course will provide applications that illustrate uses of the mathematics and point the way to needed further developments.

661 Robotics
Fall. 4 credits. Prerequisites: CS 482 and permission of instructor. Not offered every year.
3 lecs.
State-of-the-art in theoretical and experimental robotics, with an emphasis on robot-motion planning. Topics include: Task-level robot planning, collision-free path planning, grasp synthesis, modeling and propagating uncertainty, planning compliant motions for precision assembly, geometrical planning theories, motion planning with dynamics (and dynamic constraints), computational complexity of robot-motion planning, computational theories of friction, impact, and the physics of manipulation, and error detection and recovery in robotics.

662 Robotics Laboratory
Fall. 1 credit. Prerequisite: graduate standing or permission of instructor. Not offered every year.
1 lab.
Introduction to the use of equipment and techniques in a modern robotics laboratory. Includes VAL programming, force sensing, compliant motion, and mechanical assembly.

664 Machine Vision
Spring. 4 credits. Prerequisites: undergraduate-level understanding of algorithms, knowledge of differential equations, and differential and transformational geometry.
3 lecs.
An introduction to computer vision, with an emphasis on object recognition and geometric matching. 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.

671 Introduction to Automated Reasoning
Fall. 4 credits. Prerequisites: CS 611 and 681 and Mathematics 581. Not offered every year.
3 lecs.
Methods to automate reasoning in mathematics, including decision procedures, theorem provers, and formal proof tactics. Various implemented systems such as Edinburgh LCF, Cornell's Nuprl, and the Boyer and Moore theorem prover may be studied.

672 Artificial Intelligence Programming
Spring. 4 credits. Prerequisite: CS 472 or permission of instructor.
3 lecs.
Review of Common LISP programming and an overview of AI programming techniques. Discussion focuses on practical issues faced by implementors of large LISP systems. Topics may include discrimination nets, agendas, deductive retrievers, slot and filler databases, backtracking problem solvers, and truth-maintenance systems. Students will be expected to implement several of the systems discussed in class.

681 Analysis of Algorithms
Fall. 4 credits. Prerequisite: CS 381 or 481, or permission of instructor.
3 lecs.
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.

682 Theory of Computing
Spring. 4 credits. Prerequisite: CS 381 or 481, or permission of instructor.
3 lecs.
Advanced treatment of theory of computation, computational-complexity theory, and other topics in computing theory.

709 Computer Science Graduate Seminar
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.

711 Topics in Programming Languages and Systems
Spring. 4 credits. Prerequisites: CS 381 or 481, and 611, or permission of instructor. Not offered every year.
2 lecs.
Topics are chosen at instructor's discretion.

712 Topics in Programming Languages and Systems
Spring. 4 credits. Prerequisite: CS 612 or permission of instructor. Not offered every year.
2 lecs.
Topics are chosen at instructor's discretion.

713 Seminar in Systems and Methodology
Fall, spring. 4 credits. Prerequisites: CS 414 and an advanced Systems course such as CS 613, 614, 632, or 643, or permission of instructor. Not offered every year.
Discussion of contemporary issues in systems and methodology.

714 Distributed Computing
Spring. 4 credits. Prerequisites: CS 414 and an advanced systems course such as CS 613, 614, 632, or 643, or permission of instructor. Not offered every year.
2 lecs.
Principles of distributed computing and their application to fundamental problems. Considerable time will be devoted to modeling distributed computations, the theory of concurrency control, security and protection, and issues in fault tolerance (including consensus problems). Other topics may be optimal resource placement, cache management, the specification of distributed programs, and randomized protocols.

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.

717 Topics in Parallel Architectures
Fall. 4 credits. Prerequisite: CS 612 or permission of instructor. Not offered every year.
2 lecs.
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.

719 Seminar in Programming Languages
Fall, spring. 4 credits. Prerequisite: CS 611 or permission of instructor. S-U grades only.

721 Topics in Numerical Analysis
Fall. 4 credits. Prerequisite: CS 621 or 622, or permission of instructor. Not offered every year.
2 lecs.
Topics are chosen at instructor's discretion.

722 Topics in Numerical Analysis
Spring. 4 credits. Prerequisite: CS 621 or 622. Not offered every year.
2 lecs.
Topics are chosen at instructor's discretion.

729 Seminar in Numerical Analysis
Fall, spring. 1–4 credits (to be arranged). Prerequisite: permission of instructor. S-U grades only.

[**733 Topics in Information Processing**
Not offered every year.
2 lecs.
Topics are chosen at instructor's discretion.]

[734 Seminar in File Processing
Fall. Credit to be arranged. Prerequisite: CS 733 or permission of instructor. Not offered every year.]

739 Seminar in Text Processing and Information Retrieval
Fall, spring. Credit to be arranged. Prerequisite: CS 635 or permission of instructor. S-U grades only.

[743 Topics in Fault-Tolerant Distributed Computing
Prerequisites: CS 614, 643, or 714. Not offered every year.
1 lec.
A study of the latest results and an exploration of open questions in the area of fault-tolerant distributed computing. Topics may include failure models, reliable broadcasts, synchronization, knowledge, and network partitioning. This course is particularly suited to students interested in pursuing research in this area.]

747 Seminar in Program Logic and Semantics
4 credits. Prerequisite: permission of instructor. S-U grades only. Not offered every year.

749 Seminar in Systems Modeling and Analysis
Fall, spring. 4 credits. Prerequisite: permission of instructor. Not offered every year. Discussion of advanced topics in modeling and analysis of computer systems and networks, with emphasis on performance.

771 Topics in Artificial Intelligence
4 credits. Prerequisite: permission of instructor. Not offered every year.

772 Seminar in Advanced Robotics
4 credits. Prerequisite: permission of instructor. Not offered every year.

773–774—Proseminar in Cognitive Studies I and II (also Cognitive Studies, Philosophy, Linguistics, and Psychology 773–774)
Fall-spring. 2 credits.
R 1:25–2:40. Staff (taught jointly by faculty from Cornell's Cognitive Studies Program, representing fields of computer science, linguistics, philosophy, and psychology).
This is a year-long lecture-and-discussion course which 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.

779 Seminar in Machine Learning
Fall, spring. Credit to be arranged. Prerequisite: permission of instructor. S-U grades only.

781 Topics in Analysis of Algorithms and Theory of Computing
Fall. 4 credits. Prerequisites: CS 681 and 682, or permission of instructor. S-U grades only. Not offered every year.
2 lecs.
Topics are chosen at instructor's discretion.

782 Topics in Analysis of Algorithms and Theory of Computing
Spring. 4 credits. Prerequisites: CS 681 and 682, or permission of instructor. S-U grades only. Not offered every year.
2 lecs.
Topics are chosen at instructor's discretion.

783 Fundamentals of Distributed Algorithms
Spring. 4 credits. Prerequisite: A graduate course in algorithms and one in systems, or permission of instructor.
2 lecs.
A research-oriented course in distributed algorithms. Two main models of computation will be considered: the message passing (point-to-point, broadcast) and the shared-memory models. Material from the following topics will be covered: fault-tolerance, agreement, atomic broadcasts, clock synchronization, real-time issues, mutual-exclusion, concurrency control, self-stabilization, knowledge-theoretic algorithms, probabilistic algorithms, secrecy, and authentication.

789 Seminar in Theory of Algorithms and Computing
Fall, spring. 2–4 credits. Prerequisite: permission of instructor. S-U grades only.

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.

890 Special Investigations in Computer Science
Fall, spring. Prerequisite: permission of a computer science adviser. S-U grades only. Master of Science degree research.

990 Special Investigations in Computer Science
Fall, spring. Prerequisite: permission of a computer science adviser. S-U grades only. Doctoral research.

ELECTRICAL ENGINEERING

Core Courses

210 Introduction to Electrical Systems (also Engr 210)
Fall, spring. 3 credits. Prerequisites or corequisites: Mathematics 293 and Physics 213.
3 lecs and optional tutorial sections.
For description see Engineering Common Courses.

230 Introduction to Digital Systems
Fall, spring. 4 credits.
2 lecs, 5 lab experiments.
Introduction to basic analysis, design techniques, and methodology of digital systems. Boolean algebra, integrated circuit components used in digital-system implementation, codes and number systems, logic design of combinational circuits, and sequential circuits, register transfer systems, and machine organization. Laboratory experiments are performed on a Macintosh computer using a logic simulator.

301 Electrical Signals and Systems I
Fall. 4 credits. Prerequisites: a grade of at least C+ in Engr 210 and C in Mathematics 293 and 294.
3 lecs, 1 rec-computing session.
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.

302 Electrical Signals and Systems II
Spring. 4 credits. Prerequisite: EE 301.
3 lecs, 1 rec-computing session.
Linear time-invariant systems as models for electrical networks; network topology; nodal analysis, loop analysis, modified nodal analysis, and state variable analysis; unilateral Laplace transforms for solving vector differential equations; passivity and related energy storage concepts; elementary nonlinearities.

303 Electromagnetic Waves
Fall, summer co-op session. 4 credits. Prerequisites: Grades of C or better in Physics 213, 214, and Mathematics 294.
3 lecs, 1 rec.
Maxwell's equations in differential form, wave equation and the Poynting theorem. Fundamentals of electromagnetic waves with emphasis on plane waves and the effects of the medium and boundary conditions on wave propagation. Guided waves including transmission lines and rectangular waveguides. Basics of resonant cavities and simple short and dipole antennas.

304 Electromagnetic Fields and Applications
Spring. 4 credits. Prerequisites: Grades of C or better in EE 303 and EE 301.
3 lecs, 1 rec.
A deeper and broader foundation in electromagnetics than EE 303, recommended for students interested in electrophysics. Electrostatics and magnetostatics: energy and forces in static fields. Boundary value problems. Wave propagation: conducting and dielectric guiding structures. Anisotropic media such as plasma and ferrites. Dispersion of signals. Superconductors and semiconductors. Antennas and radiation: elemental radiators and linear antenna arrays. Transmitting-receiving relations. Radar and scattering cross section.

306 Fundamentals of Quantum and Solid-State Electronics
Spring. 4 credits. Prerequisites: Physics 214, Mathematics 294, and EE 303.
3 lecs, 1 rec-computing session.
Introductory quantum mechanics and solid-state physics necessary for understanding lasers and modern solid-state electronic devices. Quantum mechanics is presented in terms of wave functions, operators, and solutions of Schroedinger's equation. 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 studied include a simple metal, thermionic emission, and the p-n junction.

308 Fundamentals of Computer Engineering
Spring. 4 credits. Prerequisites: CS 100 and EE 230.
3 lecs, 1 rec-computing session.
An introduction to theoretical topics basic to computer engineering: discrete mathematics; structured computer organization; data structures and algorithms; and computer arithmetic. Practical applications of these concepts.

310 Introduction to Probability and Random Signals
Spring. 4 credits. Prerequisite: Mathematics 294.
3 lecs, 1 rec-computing session.
Introduction to the theory of probability as a basis for modeling random phenomena and signals, calculating the response of systems incorporating these models, and making estimates, inferences, and decisions in the presence of chance and uncertainty. Applications of these models will be given in such areas as communications, control, and device modeling. Specific topics include the basic concept of probability and its presentations through densities, cumulative distribution functions, and characteristic functions; conditional probability; independence; scalar and vector random variables and nonlinear transformations of data; expectation, conditional expectation, moments, correlation; laws of large numbers and central limit theorem; linear least mean square estimation; Bayes decision making.

315 Electrical Laboratory I
Fall. 4 credits. Prerequisite: a grade of at least C+ in Engr 210.
2 lecs, 2 labs.
Basic electrical and electronic instrumentation and measurements involving circuits and fields of both active and passive elements; an experimental introduction to solid-state theory and devices. Introduction of the personal computer as a laboratory aid.

Computer Engineering

230 Introduction to Digital Systems
Fall, spring. 4 credits.
For description see Core Courses.

423 Computer Methods for Circuit Simulation
Fall. 4 credits. Prerequisite: EE 302. Satisfies undergraduate computer-applications requirement.
3 lecs, open lab.
Numerical techniques presented in the context of circuit simulation. Solution of linear and nonlinear algebraic equations; integration; solution of ordinary differential equations; alternative forms of circuit-equation formulation. Starting from a program to simulate simple, linear passive, steady-state circuits, the instructor will add, and the students improve on, procedures that will finally result in a nonlinear transient integrated-circuit simulator that involves most of the techniques discussed in class.

445 Computer Networks and Telecommunications I
Fall. 3 credits. Prerequisites: EE 308, a course in probability, and programming at the level of CS 211.
3 lecs.
Methods and approaches in the design, analysis, and implementation of local area networks and public data networks; circuit switching, packet switching; carrier-sense multiple access with collision detection, token passing; ethernets, busses, and rings; roles and functions of protocols; layering and ISO models.

475 Computer Structures
Fall. 4 credits. Prerequisite: EE 308 or EE 230 and CS 314.
3 lecs, 1 lab.
Methods of designing digital computers and the hardware-software interface to the systems they function with. Topics will include types of control sequencers, memory and I/O organization and interfacing, interrupt hardware design, floating-point hardware and basic architectural alternatives. Laboratory groups will design and build a small digital computer. User-programmable logic devices will be employed for circuit implementation.

476 Microprocessor Systems
Spring. 4 credits. Prerequisite: EE 475.
3 lecs, 1 lab.
System design using microprocessors. Hardware and software techniques employed in interfacing. Assembly language and Pascal programs for interfacing and control of interfaced devices. Study of different microprocessor architectures, memory management, multiprogramming, and multiprocessing. Development systems and user-programmable logic devices will be employed in the laboratory for interfacing the microcomputer to hardware.

524 Differential Equation Numerical Methods for the Electrical Engineer
Spring. 4 credits. Prerequisites: EE 301 and EE 303. EE 423 is helpful. A working knowledge of a scientific programming language is required. Open to both undergraduates and graduates. Satisfies undergraduate computer applications requirement.
3 lecs, open lab.
Numerical methods for ordinary and partial differential equations are presented using examples from different areas of electrical engineering. Examples include semiconductor-device simulation, plasma simulation, propagation of solitons in optical fibers, and the modeling of electrostatic fields in micromechanical devices. Numerical methods include particle-in-cell simulation techniques; spectral methods; elementary parabolic, elliptic, and hyperbolic methods; and the boundary-element method. The fundamental notions of accuracy and error, consistency, stability, and convergence are discussed.

539 VLSI Digital-System Design
Fall and spring. 6 credits (must be taken both semesters). Prerequisite: EE 475 or equivalent.
Fall: 3 lecs, 1 computing sec; spring: 1 lec, 1 lab.
Custom VLSI design as seen by a system designer. Switches as logic devices, MOS transistor, MOS logic design, two-phase clocking, stick diagrams, cell layout, regular control structures, simulation, performance analysis, RC timing model, system design for performance, design for testing, semicustom design, systolic arrays, CAD design tools. A chip design project and design report are required for fall semester. CAD tools are used extensively. Chips are tested for functionality and performance, and the design report is revised during the spring semester.

541 Advanced Computer Architectures
Fall. 3 credits. Prerequisite: EE 308 or permission of instructor.
Design and evaluation of processor architectures are examined in the light of actual implementations of both large-scale and small-scale systems. Topics include microprogramming, parallel and pipelined architectures, interleaved memories, cache and virtual memories, I/0 processors, vector and array processors, protection mechanisms, and RISC architectures.

542 Parallel Processing
Spring. 3 credits. Prerequisite: EE 541 or permission of instructor.
3 lecs.
Computer architecture for parallel processors that are designed to provide a high computation rate for large scientific problems; primary emphasis on image processing and highly parallel VLSI-based systems. Other applications considered include signal processing and the solution of PDEs. Performance, processor interconnections, algorithms, programming techniques, and fault tolerance will be discussed. Architecture types to be considered include binary-array processors, pipeline processors, inner-product computers, systolic arrays, and MIMD systems.

543 VLSI Architectures and Algorithms
Fall. 3 credits. Prerequisite: EE 476 or permission of instructor.
3 lecs.
Since the advent of VLSI, the cost of processing logic is no longer a fundamental constraint on the design of computer architectures. Problems that once were computationally intractable can now be solved on arrays of thousands or even tens of thousands of processors. This course addresses the important question: What are the optimal VLSI structures and algorithms for specific classes of problems? The architectures we will examine include systolic arrays, mesh-connected processors, and data-flow computers; special attention will be given to problems that arise in real-time signal processing.

546 Computer Networks and Telecommunications II
Spring. 3 credits. Prerequisite: EE 545 or permission of instructor.
3 lecs.
Introduction to Integrated Service Digital Network (ISDN); circuit switching fundamentals; time division architectures; packet switching architectures; integration of circuit and packet switching; evolution from ISDN to Broadband ISDN.

[547 Computer Vision
Fall. 3 credits. Prerequisites: EE 302 and 475 or 425, or permission of instructor.
3 lecs. Not offered 1990–91.
Computer acquisition and analysis of image data with emphasis on techniques for robot vision. Computer vision is the construction of explicit meaningful descriptions of physical objects from images. 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.]

548 Image Processing
Spring. 4 credits. Prerequisite: EE 301 or permission of instructor.
3 lecs.
Image formation and perception, digitization, image coding, image enhancement, image restoration, computerized tomography, optical processing, image analysis. The programming of several image-processing algorithms will be required.]

563 Communication Networks
Fall. 4 credits.
For description see Communication and Information Systems.

593 RISC Microprocessor Design (also CS 616)
4 credits over two semesters. Prerequisite: EE 539 or consent of instructors.
L. K. Grover and K. K. Pingali.
RISC (Reduced Instruction Set Computers) is the newest trend in microprocessor architecture—every leading microprocessor manufacturer including Motorola and Intel has announced RISC microprocessors. In this course, we will design and fabricate CAYUGA, a pipelined RISC microprocessor on a VLSI chip. Students will be given the instruction-set specification of the CAYUGA processor. During the course, they will perform the VLSI layout and simulation of the design. The processor will then be fabricated by MOSIS, after which it will be tested to verify that it meets design goals.

644 Fault-Tolerant Computing
Spring. 3 credits. Prerequisites: EE 541 and 543.
The discipline of fault-tolerant computing deals with digital systems that operate in applications where the cost of failure is high. Effective and efficient techniques are required for tolerating failures in complex digital systems. The real-time needs of many signal processing problems have led to the development of special-purpose systolic arrays. This course covers general fault-tolerance techniques such as masking redundancy and error detecting and correcting codes, with particular emphasis on those suitable for systolic computing.

Circuits, Systems, and Signal Processing

210 Introduction to Electrical Systems
Fall, spring. 3 credits.
For description see Engineering Common Courses.

230 Introduction to Digital Systems
Fall, spring. 4 credits.
For description see Core Courses.

301 Electrical Signals and Systems I
Fall. 4 credits.
For description see Core Courses.

302 Electrical Signals and Systems II
Spring. 4 credits.
For description see Core Courses.

318 Electric and Electromechanical Circuits and Systems
Spring. 4 credits. Prerequisite: EE 315. Integrated lectures and lab.
Concepts and methods for design, construction, testing, and analysis of a variety of electronic circuits and for modeling and analysis of electromechanical devices such as speakers, solenoids, and a variety of motors. Applications of single-input/single-output classical feedback-control principles illustrated through the design and testing of a DC motor (PWM driven) positional system.

423 Computer Methods for Circuit Simulation
Fall. 4 credits.
For description see Computer Engineering.

425 Digital Signal Processing
Fall. 4 credits. Prerequisite: EE 301.
3 lecs, 1 lab.
Fundamentals of signal analysis, review of Fourier, Laplace, and Z transforms. Sampling theory. Discrete Fourier transform properties and computation (FFT). Digital filter design; the approximation problem for FIR and IIR filters, the realization problem–finite word-length limitations and filter structures.

426 Applications of Signal Processing
Spring. 3 or 4 credits. Prerequisite: EE 425.
1 lec, 2 labs.
Applications of signal processing, including signal analysis, filtering, and signal synthesis. The course is laboratory oriented and emphasizes individual student projects. Design is done with signal-processing hardware and by computer simulation. Topics include filter design (principally digital filtering) and spectral analysis as well as speech coding, speech processing, digital recording, adaptive noise cancellation, and digital signal synthesis.

521 Theory of Linear Systems
Fall. 4 credits. Prerequisite: EE 302 or permission of instructor. Recommended: a good background in linear algebra and differential equations.
3 lecs.
State-space and input-output linear systems. Transition matrices, matrix exponential functions, the Cayley-Hamilton theorem, and the Jordan form. Controllability, observability, stability, realizability. At the level of *Linear Systems*, by T. Kailath.

522 Theory of Nonlinear Systems
Spring. 4 credits. Prerequisites: EE 521 or a solid background in linear algebra strongly recommended but not required.
A fairly rigorous introduction to nonlinear systems, including nonlinear differential equations (existence and uniqueness theorems); flows; stability of equilibria and periodic orbits; Lyapunov functions; the Circle Criterion and Popov's Criterion; the Poincaré-Bendixson Theorem.

[526 Advanced Signal Processing
Spring. 4 credits. Prerequisites: EE 411 and EE 425. Not offered 1990–91.
3 lecs, 1 lab.
Sampling and signal reconstruction. Approximation theory with 1 [sub p] and Chebyshev norms. Linear inversion theory. Exponential signal modeling. Spectral estimation. Radon transform.]

528 Multisensor Digital Signal Processing
Spring. 4 credits. Prerequisite: EE 301, 411, 425 recommended.
Addresses signal processing techniques for the coordinated use of data derived from an array of sensors. Application areas for sensor arrays include radar, geophysics, speech enhancement, and satellite comunications. We will discuss propagation and sensor models, beamforming, sidelobe cancellers, source location and direction finding, adaptive detection and estimation, computational approaches (RLS, LMS, and square root) and architectures (systolic arrays and other concurrent schemes). Assignments will involve computer simulations.

548 Image Processing
Spring. 4 credits.
For description see Computer Engineering.

674 Adaptive Parameter Estimation Theory
3 credits.
For description see Power and Control Systems.

679 Advanced Topics in Systems and Control
1–3 credits.
For description see Power and Control Systems.

Communication and Information Systems

310 Probability and Random Signals
Spring. 4 credits.
For description see Core Courses.

411 Random Signals in Communications and Signal Processing
Fall. 3 credits. Prerequisite: EE 302 and 310 or equivalent.
3 lecs.
Introduction to probability models for random signals in discrete and continuous time; Markov chains, Poisson process, queuing processes, wide-sense stationary processes and power spectral densities, Gaussian random process, including the narrowband case. Electrical engineering phenomena described by such models (e.g., communications channel noise, queues that form in multiple-access telecommunications systems). Response of linear and nonlinear systems to random signals. Elements of estimation and inference as they arise in communications and digital signal processing systems (e.g., problems of extraction of signals from noise via Wiener filtering, power spectral density estimation).

445 Computer Networks and Telecommunications I
Fall. 3 credits.
For description see Computer Engineering.

468 Communications and Signal Processing
Spring. 4 credits. Prerequisite: EE 301 or 521, and 411 or equivalent.
3 lecs, 1 rec.
Analog signal representation and filtering using Fourier and Hilbert transform techniques. Varieties of amplitude modulation (AM, DSBSC, SSB, VSB, QAM) and their demodulators. Frequency modulation and demodulation. Demodulation of AM and FM in the presence of noise. Sampling theorems and aliasing. Pulse amplitude modulation. Quantization for A/D conversion. Pulse code modulation. Elements of optimal signal parameter estimation. Application to commercial broadcasting and data transmission.

546 Computer Networks and Telecommunications II
Spring. 3 credits.
For description see Computer Engineering.

561 Error-Control Codes
Fall. 3 credits. Prerequisite: EE 301 or EE 521 or equivalent. A strong familiarity with linear algebra is assumed.
3 lecs.
An introduction to the theory of error-control codes: linear block codes, convolutional and other trellis codes. Hamming codes, minimum distance, standard array, minimum-distance decoding, cyclic codes. The dual of a code. Methods of shortening and combining codes. Hamming and Singleton bounds for error-correcting codes. Algebra: groups, rings, and fields with special emphasis on Galois or finite field theory. The construction and decoding of Bose-(Ray) Chaudhuri-Hocquenghem (BCH) and Reed-Solomon (RS) codes. Algebraic description of binary convolutional codes. Decoding algorithms and construction of Euclidean distance trellis codes.

562 Fundamental Information Theory
Spring. 3 credits. Prerequisite: EE 310 or equivalent.
3 lecs.
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.

563 Communication Networks
Fall. 4 credits. Prerequisite: EE 310 or permission of instructor.
3 lecs.
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 and wide area communication networks: TDMA, FDMA, ALOHA, slotted ALOHA, Ethernet, reservation, tree, and interval-searched contention resolution protocols. Flow control and capacity assignment algorithms for wideband, robust networks. Examples drawn from packet radio, T1 networks, and satellite communications.

564 Decision Making and Estimation
Spring. 4 credits. Prerequisite: EE 411.
An introduction to those methods of making rational decisions and inferences and of forming estimates that are central to problems of communications, detection, and statistical signal processing. Topics covered are drawn from utility theory and rational preferences; 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.

566 Queuing Networks
Spring. 4 credits. Prerequisite: EE 411 or equivalent.
Single-class and multiclass queuing network models of communication networks and computer networks. Little's formula. Jackson networks. Quasi-reversibility. Product-form networks. Output theorem. Analysis of sojourn times. Insensitivity. Server allocation and optimal routing problems. Bandit problem. Fluid approximation. Light traffic approximation. Heavy traffic approximation. Static and dynamic control of queuing networks. Regenerative simulation of performance measures. Fast simulation techniques. Perturbation analysis.

567 Communication Systems II
Fall. 4 credits. Prerequisites: EE 411, 468.
This course presents the fundamental principles of the theory of digital communication. Analytical and computational tools required to understand the principles of modern data conversion, transmission, and storage systems are presented. While examples of systems from the "real" world are described, the emphasis of the course is on the fundamental theory involved in the design of digital communication systems.

577 Artificial Neural Networks
Fall. 3 credits. Prerequisites: EE 310; EE 411 recommended.
Artificial neural networks are brainlike in being formed out of many highly interconnected nonlinear memoryless elements. Probability theory will provide the primary analytical approach to design and analysis of neural networks. The course will cover aspects of feed-forward nets (multilayer perceptrons) that can serve as pattern classifiers, decision-making devices, and controllers, as well as aspects of recurrent/feedback/Hopfield nets that can serve as associative memories and combinatorial optimizers. Students will have an opportunity to explore the behavior of neural networks through computer simulation and to present an article from the current literature.

664 Foundations of Inference and Decision Making
Spring. 3 credits. Prerequisite: a course in probability and some statistics, or permission of instructor. Not offered every year.
3 lecs.
An examination of methods for characterizing uncertainty and chance phenomena and for transforming information into decisions and optimal systems. Discussion of the foundations of inference includes topics drawn from comparative probability, interval-valued probability, quantitative probability, relative frequency interpretations, computational complexity, randomness, classical probability and invariance, induction, and subjective probability.

668–669 Random Processes in Electrical Systems
668, fall; 669, spring. 3 credits each term.
Advanced topics in the general area of randomness and uncertainty and their relevance to the analysis and design of electrical systems.

Power and Control Systems

318 Electric and Electromechanical Circuits and Systems
Spring. 4 credits.
For description see Circuits, Systems, and Signal Processing.

451–452 Computer-Aided Analysis of Electric Power Systems I and II
451, fall; 452, spring. 4 credits each term. Prerequisite: EE 302.
3 lec-recs, 1 lab-computing session.
The so-called second-generation and third-generation simulation tools and their computer implementation for large-scale circuits and systems. Modeling of electric power systems for load-flow, stability, economic-dispatch, control, and optimal-power-flow studies. Special properties of electric power systems that enhance the efficiency of simulation tools used for their analysis. The Kettering Power System Laboratory's digital computer is used as a dynamic "laboratory."

471 Feedback Control Systems
Fall. 4 credits. Prerequisite: EE 302 or M&AE 326, or permission of instructor.
3 lecs, open lab.
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 PID, root-locus, frequency response, and algebraic pole placement. Computer-aided design laboratory examines modeling and control of a computer-simulated dynamic industrial process.

[555 Advanced Power Systems Analysis I
Fall. 3 credits. Prerequisites: EE 302 and concurrent registration in 451, or permission of instructor. Not offered 1990–91.
Analysis of power-system components. These components include rotating machines and systems for excitation control, automatic voltage regulation, boiler-turbine control, and speed regulation, as well as ancillary three-phase networks. Emphasis on derivation of mathematical models from first principles; development of algorithms for the formation of applicable network matrices.]

[556 Advanced Power Systems Analysis II
Spring. 3 credits. Prerequisite: EE 555 or permission of instructor. Not offered 1990–91.
Computer methods in power systems applied to short-circuit studies, load-flow studies, transient-stability studies, economic dispatch, and security load flows. Use of sparse-matrix techniques. Comparison of algorithms for digital relaying. State-estimation algorithms. Emphasis on the use of the digital computer in the planning and operation of large-scale power systems. At the level of *Computer Methods in Power System Analysis*, by Stagg and El-Abiad.]

564 Decision Making and Estimation
Spring. 4 credits.
For description see Communication and Information Systems.

572 Digital Control Systems
Spring. 4 credits. Prerequisite: EE 471 or permission of instructor.
3 lecs, open lab.
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, algebraic-control design, and simultaneous identification and control. Assignments will consist of reports on computer-aided controller design and digitally-simulated evaluation.

573 Optimal Control and Estimation for Continuous Systems
Fall. 4 credits. Prerequisite: EE 521 or permission of instructor. Not offered every year.
3 lecs.
Control system design through parameter optimization, with and without constraints. The minimum principle; linear regulations, minimum-time and minimal-fuel problems. Computational techniques; properties of Lyapunov and Riccati equations.

574 Estimation and Control in Discrete Linear Systems
Spring. 4 credits. Prerequisites: EE 521 and 411, or permission of instructor.
3 lecs.
Optimal control, filtering, and prediction for discrete-time linear systems. Approximation on discrete point sets. The principle of optimality. Kalman filtering. Stochastic optimal control.

664 Foundations of Inference and Decision Making
Spring. 3 credits.
For description see Communication and Information Systems.

674 Adaptive Parameter Estimation Theory
3 credits. Prerequisites: EE 521 and either 526 or 572, or permission of instructor. Recommended: EE 522. Not offered every year.
3 lecs.
Fundamental concepts of adaptive parameter estimation theory as applicable to adaptive filtering, adaptive control, and system identification. Analytical tools are drawn primarily from nonlinear, time-varying feedback-system stability theory. Applications considered include telephony echo cancellation, noise cancelling, differential pulse code modulation, channel equalization, model-following control, and pole placement. Assignments will consist of reports on analysis and simulation studies of adaptive parameter-estimator behavior.

679 Advanced Topics in Systems and Control
1–3 credits. Prerequisite: permission of instructor. Not offered every year.
Topics include robotics, nonlinear feedback system stability, multivariable control, and qualitative theory on nonlinear systems.

Solid-State Electronics

306 Fundamentals of Quantum and Solid-State Electronics
Spring. 4 credits.
For description see Required Courses.

412 Applied Solid-State Physics
Spring. 4 credits. Prerequisite: EE 306.
3 lecs, 1 rec.
Review of basic solid-state concepts (lattice, primitive cell, reciprocal lattice, Brillouin zone). Lattice vibrations. The diatomic chain. Polarity of waves. Binding of crystals. Thermal properties of insulators and metals. Effective mass tensor. Magnetic flux quantization and the Fermi surface in metals. Plasmons, polaritons, and polarons. Charge-carrier scattering. Optical properties. Kramers-Kronig relations. Elements of superconductivity. Dia- and ferroelectric materials. Dia-, para-, ferro-, and antiferromagnetism.

431–432 Analysis and Design of Integrated Circuits
431, fall; 432, spring. 4 credits each term. Prerequisites: EE 301 and 315. Concurrent registration in EE 435 is encouraged.
3 lecs, 1 lab.
Analysis and design of analog and digital circuits using semiconductor devices, with emphasis on integrated circuits in bipolar and MOS technologies. Device models for circuit analysis; common circuit configurations; DC analysis, frequency response and speed limitations; feedback and noise sources. Case studies such as design of high-frequency or operational amplifiers and semiconductor memory, reinforced by laboratory and design projects. At the level of *Analysis and Design of Analog Integrated Circuits*, by Gray and Meyer, and *Analysis and Design of Digital Integrated Circuits*, by Hodges and Jackson.

433 Microwave Integrated Circuits
Fall. 4 credits; may be taken for 3 credits without laboratory. Prerequisites: EE 303 and EE 306.
3 lecs, 1 lab.
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.

435–436 Semiconductor Electronics
435, fall; 436, spring. 4 credits each term; may be taken for 3 credits without laboratory only with permission of instructor. Prerequisites: EE 306 and 316, or equivalent.
3 lecs, 1 lab.
Semiconductor electronics from point-contact transistor to VLSI and beyond. Fall term: electronic characteristics of semiconductors, carrier transport, band diagrams, semiconductor interfaces; pn-junction diode, Si bipolar transistor (BJT), Si MOS transistor (MOSFET), integrated Si structures such as inverters (NMOS, CMOS). Spring terms: GaAs J-FET, Schottky diode, GaAs metal-semiconductor FET (MESFET), AlGaAs/GaAs modulation-doped FET (MODFET), heterojunction bipolar transistor (HBT); semiconductor lasers and optical detectors, integrated GaAs structures; computer simulation of devices; limits and future of semiconductor electronic devices.

524 Differential Equation Numerical Methods for the Electrical Engineer
Spring. 4 credits.
For description see Computer Engineering.

534 Microwave Semiconductor Devices
Spring. 4 credits, may be taken for 3 credits without lab. Prerequisites: EE 433 and EE 435.
3 lecs, 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.

535 Semiconductor Physics
Fall. 4 credits. Prerequisites: EE 304 and 407, or permission of instructor.
3 lecs.
Foundations of semiconductor physics for the description of carrier transport and optical characteristics of semiconductor materials and structures. Crystal structure and symmetry, energy-band structures, statistics, effective mass theorem, classical transport, scattering, high-field transport, quantum transport, optical absorption and reflection, photoconductivity, light generation, deep levels, and surface and interface phenomena. On or above the level of *Fundamentals of Semiconductor Theory and Device Physics*, by S. Wang.

536 VLSI Technology
Spring. 4 credits. Prerequisite: EE 435 or permission of instructor.
3 lecs, 1 lab.
Processing technology for high-density silicon integrated circuits for CMOS, BiCMOS, and ECL. Lithography, oxidation, diffusion, ion implantation, thin-film deposition, dry etching, multilevel interconnect, process integration, manufacturing yield, integrated-circuit reliability, future of high-density VLSI. Laboratory includes actual device fabrication in a clean room, measurements, and process simulations. On the level of *VLSI Technology*, edited by S. M. Sze.

537 Physical Design of High-Speed Computers
Fall. 4 credits. Prerequisites: EE 230 and 431 or 435; or permission of instructor. Recommended companion course: MS&E 463.
Integration of computer structures from integrated circuits to modules, boards, and full computer systems, from workstations to supercomputers. Computer packaging architectures; high-speed electrical and optical signal distribution; power distribution and thermal management; functional architecture; manufacturing, measurement, and simulation methods; case studies on workstations, mainframes, and supercomputers; fundamental limits. On the level of *Principles of Electronic Packaging*, edited by Seraphim, Lasky, and Li. Lectures by outside speakers from the computer industry.

538 Introduction to III–V Compound Semiconductor Materials
Spring. 3 credits. Prerequisites: EE 407 and 436.
J. R. Shealy.
An introduction to III–V compound semiconductor materials and their crystal growth technologies. Topics include the modern epitaxial growth technologies, Molecular Beam Epitaxy and Organometallic Vapor Phase Epitaxy; common methods used for the evaluation of compound semiconductor materials, including Raman spectroscopy. Emphasis is placed on the materials' properties and the related growth and characterization techniques that currently support a variety of research topics in new semiconductor devices.

539 VLSI Digital-System Design
Fall and spring. 6 credits.
For description see Computer Engineering.

636 Advanced Solid-State Devices
Spring. 3 credits. Prerequisite: EE 535 or equivalent.
3 lecs.
A fundamental analysis of device operation, with emphasis on operational limits. Effects of band structure, low- and high-field transport characteristics, secondary ionization, transferred electron effects, and the details of junction and contact technology relevant to devices at the limits of microfabrication technology. Applications to microwave amplification, generation, and broadband optical detection, including stability, nonlinearity, and noise.

638 Advanced Semiconductor Devices and Processes
Fall. 4 credits. Prerequisite: EE 535, EE 636, or permission of instructor. Not offered every year.
3 lecs, special project or term paper.
Advanced topics in solid-state electronic-device physics, fabrication methods, and materials for high-density silicon VLSI and high-speed compound semiconductor technologies. Concepts developed in EE 535 and 636 are applied to current state-of-the-art topics. On the level of IEEE Transactions on Electron Devices, *Journal of Applied Physics*, and current conference proceedings.

Quantum and Opto-Electronics

306 Fundamentals of Quantum and Solid-State Electronics
Spring. 4 credits.
For description see Core Courses.

407 Quantum Mechanics and Applications
Fall. 4 credits. Prerequisite: EE 306.
3 lecs, 1 rec.
Fundamentals of quantum mechanics: theory of angular momentum, time-independent and time-dependent perturbation theory, and interaction of radiation with matter. Elementary considerations of the structure of atoms, molecules, and solids. Applications to semiconductors, spectroscopy of atoms and molecules, and lasers.

430 Lasers and Optical Electronics
Fall. 3 credits. Prerequisite: EE 306 or equivalent.
3 lecs, 1 rec-lab.
An introduction to the operation of stimulated-emission devices such as lasers and devices based on linear and nonlinear optics. Material covered includes diffraction-limited optics, propagation of Gaussian laser 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 as time permits.

437 Fiber and Integrated Optics
Spring. 3 credits lecture only, 4 credits with lab. Prerequisite: EE 306. EE 304 and 430 or equivalents are strongly recommended.
3 lecs, 1 lab–computing session; lab optional.
A detailed treatment of the physical principles of fiber optics, integrated optics, and optical applications to communication and sensing. Topics include mode structure in waveguides, mode coupling, dispersion and bandwidth limitations, optical sources based on semiconductors, detectors and noise, modulation techniques, nonlinear effects in fibers, and optical sensors. Laboratory includes experiments relevant to lasers and fiber optics.

524 Differential Equation Numerical Methods for the Electrical Engineer
Spring. 4 credits.
For description see Computer Engineering.

531 Quantum Electronics I
Fall. 4 credits. Prerequisites: EE 306 and 407, or Physics 443.
3 lecs, 1 computing session.
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.

532 Quantum Electronics II
Spring. 4 credits. Prerequisite: EE 531 or permission of instructor.
3 lecs, 1 lec–computing session.
A continuation of EE 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.

535 Semiconductor Physics
Fall. 4 credits.
For description see Solid-State Electronics.

Plasmas and Large-Scale Fluids

481 Experimental Plasma Physics and Gas Discharges
Fall. 4 credits. Prerequisite: EE 304 or A&EP 356 or equivalent. Fulfills electrical engineering laboratory requirement and constitutes an M.Eng.(Electrical) course pair with EE 480 or 484.
3 lecs, 1 lab.
Theory and practice of generation, control, and diagnostics of plasmas and intense particle beams. Coordinated lectures and nine experiments and a field trip. Plasma breakdown, collisions, diffusion, sheaths. Discussion of macroscopic and microscopic measurements. Reflex discharge, vacuum technology, plasma probing. Electromagnetic and space-charge-wave propagation and scattering. Microwave and optical radiation. Intense particle beams. Methods for data collection and analysis.

484 Introduction to Controlled Fusion: Principles and Technology (also M&AE 559 and NS&E 484)
Spring. 3 credits. Prerequisites: EE 301 and 303, or permission of instructor. Intended for seniors and graduate students.
3 lecs.
For description see NS&E 484.

524 Differential Equation Numerical Methods for the Electrical Engineer
Spring. 4 credits.
For description see Computer Engineering.

580 Applied Electrodynamics
3 credits. Prerequisites: EE 303 and EE 304, or a grade of B or better in EE 303.
Selected topics in contemporary electrodynamics with emphasis on applications. Theory, design, and uses of high-power microwave devices such as gyrotrons, CARMs, free-electron lasers, and traveling-wave tubes. Electromagnetic waveguide and cavity modes, charged-particle orbit theory, particle dynamics in electromagnetic fields, field transforms, electron-beam generation and equilibria including self-field effects, waves on beams, low- and high-power microwave devices and their applications. At the level of *Microwave Engineering and Applications*, by O. P. Gandi.

581 Introduction to Plasma Physics (also A&EP 606)
Fall. 4 credits. First-year graduate-level course; open also to exceptional fourth-year students with permission of instructor. Prerequisites: EE 303 and 304, or equivalent.
3 lecs.
Plasma state; motion of charged particles in fields; collisions, coulomb scattering; transport coefficients, ambipolar diffusion, plasma oscillations and waves; hydromagnetic equations; hydromagnetic stability and microscopic instabilities; test particle in a plasma; elementary applications. At the level of *Plasma Physics for Nuclear Fusion*, by Miyamoto.

582 Advanced Plasma Physics (also A&EP 607)
Spring. 4 credits. Prerequisite: EE 581.
3 lecs.
For description see A&EP 607.

583 Electrodynamics
Fall. 4 credits.
For description see Fields, Waves, and Antennas.

[585 Atmospheric and Ionospheric Physics (also Astronomy 575)
Fall. 3 credits. Offered alternate years. Not offered 1990–91.
Energy-balance and thermal structure of neutral atmospheres. Elements of circulation theory. Waves and instabilities. Coupling of lower atmospheres to upper atmospheres. Observations of the terrestrial atmosphere and of the other planets. Physical processes in the earth's ionosphere and magnetosphere. Production, loss, and transport of charged particles. Electric fields. Coupling of neutral-atmosphere dynamics with electric fields and charged-particle transport. Diagnostic techniques, including radar and in situ observations. The equatorial electrojet. Observations of ionospheres on the other planets.]

[586 Solar Terrestrial Physics (also Astronomy 576)
Spring. 3 credits. Offered alternate years. Not offered 1990–91.
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.]

587 Introduction to Antennas and Radar
Fall. 3 credits. Prerequisites: EE 301 and 304 (or at least a B in 303). Open to qualified undergraduates.
For description see Fields, Waves, and Antennas.

588 Electromagnetic Wave Propagation II
Spring. 3 credits. Prerequisites: EE 587 and 581, or permission of instructor.
3 lecs.
For description see Fields, Waves, and Antennas.

589 Magnetohydrodynamics
3 credits. Prerequisite: EE 581. Offered upon sufficient demand.
The theory of ideal and nonideal magnetohydrodynamical equations with emphasis on application to controlled thermonuclear fusion. Topics: derivation and domain of applicability; invariants; waves, equilibrium and normal-mode stability analysis; continuous spectrum; energy principle and applications to confinement geometries; nonideal effects, resistivity, finite Larmor radius stabilization. Selected additional topics such as dynamo theory or MHD turbulence.

681 Kinetic Theory (also A&EP 761)
Fall. 3 credits. Prerequisite: EE 407, Physics 561, or permission of instructor.
3 lecs.
Classical, quantum, and relativistic kinetic theory, Liouville equation, Prigogine and Bogoliubov analysis of the BBKGY sequence. Master equation, density matrix, Wigner distribution. Derivation of fluid dynamics. Transport coefficients. Boltzmann, Krook, Fokker-Planck, Landau, and Balescu-Lenard equations. Properties and theory of the linear Boltzmann collision operator. The relativistic Maxwellian. At the level of *Introduction to the Theory of Kinetic Equations*, by Liboff.

682 Nonlinear Phenomena in Plasma Physics
Fall. 3 credits. Prerequisite: EE 582. Offered alternate years.
Single-particle motion, multiple-time-scale analysis and ponderomotive effects, weakly nonlinear waves and solitons, nonlinear Vlasov phenomena, quasilinear theory, resonance broadening and resonant mode-mode coupling, statistical theories of plasma turbulence, recent developments in stochasticity and chaos in plasma physics.

685 Solar Plasma Physics
Fall. 3 credits.
This course will be coordinated with the two courses on upper atmospheric physics, EE 585 and 586, to provide an integrated view of solar-terrestrial physics for the graduate student intending a research career in space plasma physics. A thorough understanding of electromagnetic theory and some knowledge of fluid mechanics and plasma physics at the level of EE 581 and 582 are assumed.

Fields, Waves, and Antennas

303–304 Electromagnetic Fields and Waves
303, fall; 304, spring. 4 credits each semester.
For description see Core Courses.

316 High-Frequency and Microwave Fundamentals
Spring. 4 credits. Prerequisites: EE 301, 303, and 315.
3 lecs, 1 lab.
Laboratory and design studies in high-frequency and fast-pulse circuits, microwaves and electro-optics. Technical report writing. Eight experiments and two design projects.

433 Microwave Integrated Circuits
Fall. 4 credits; may be taken for 3 credits without laboratory. Prerequisites: EE 303 and EE306.
For description see Solid-State Electronics.

534 Microwave Semiconductor Devices
Spring. 4 credits. Prerequisites: EE 433 and 435.
3 lecs, 1 lab. For description see Solid-State Electronics.

583 Electrodynamics
Fall. 4 credits. Prerequisite: EE 301 and EE 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.

584 Microwave Theory
Spring. 4 credits. Prerequisites: EE 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.

587 Introduction to Antennas and Radar
Fall. 3 credits. Prerequisites: EE 301 and 304 (or at least a B in 303). Open to qualified undergraduates.
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. Pulse compression principles and the ambiguity function; synthetic aperture radars and remote sensing from aircraft and satellites; over-the-horizon (OTH) radars and ionospheric propagation effects; radar astronomy techniques, including range-Doppler mapping of planets and the problem of overspread targets.

[588 Advanced Electromagnetic Wave Propagation and Scattering
Spring. 3 credits. Prerequisite: EE 587 or permission of instructor. Offered alternate years. Not offered 1989–90.
3 lecs.
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.]

General

250 Technology in Western Society (also Engr 250)
Fall. 3 credits. Approved for humanities distribution.
For description see Engineering Common Courses.

292 The Electrical and Electronic Revolutions (also Engr 292)
Spring. 3 credits.
For description see Engineering Common Courses.

360 Ethical Issues in Engineering
Spring. 3 credits. A social science elective for engineering students. Open to juniors and seniors.
3 lecs.
For description see Engineering Common Courses.

480 Thermal, Fluid, and Statistical Physics for Engineers
Spring. 3 credits. Prerequisite: Physics 214.
Extensive review of thermodynamic principles. Elementary theory of transport coefficients. Elements of fluid dynamics. Shock waves. Central-limit theorem. Random walk. Electrical noise. Fluctuation-dissipation theorem. Quantum and classical statistics. Black-body radiation. Thermal properties of solids. Kramers-Kronig relation. Elementary descriptions of the p-n junction. Shockley equation, superfluidity, superconductivity, and the laser.

491–492 Senior Project
491, fall; 492, spring. 1–8 credits.
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.

495–496 Special Topics in Electrical Engineering
1–4 credits.
Seminar, reading course, or other special arrangement agreed on by the students and faculty members concerned.

591–599 Graduate Topics in Electrical Engineering
1–4 credits.
Seminar, reading course, or other special arrangement agreed on by the students and faculty members concerned.

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. Report required.

693–694 Master of Engineering Design
693, fall; 694, spring. 1–10 credits each term. 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 numbers.

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.

791–792 Thesis Research
791, fall; 792, spring. 1–15 credits. For students enrolled in the master's or doctoral program.

GEOLOGICAL SCIENCES

Freshman and Sophomore Courses

101 Introductory Geological Sciences
Fall, spring. 3 credits.
2 lecs, 1 lab, field trips, evening exams in the fall term. Fall, W. B. Travers; spring, J. M. Bird.
This course teaches observation and understanding of the earth, including oceans, continents, coasts, rivers, valleys, glaciated regions, earthquakes, volcanoes, and mountains; theories of plate tectonics; and the origin, discovery, and development of mineral and water resources. The lab teaches use of topographic and geologic maps and recognition of minerals and rocks and includes field trips to Cascadilla Gorge, Fall Creek, and Enfield Glen.

102 Evolution of the Earth and Life
Spring. 3 credits. Prerequisite: Geol 101 recommended.
2 lecs, 1 lab, field trips, weekly quizzes, no midterm. J. L. Cisne.
The story of the earth and life in terms of evolutionary processes and the global economy and material. The planet as a by-product of stars' evolution. Plate tectonics, continental drift, and their implications for life, fossil fuels, and climate. The greenhouse effect and its few-billion-year history. Evolution of life, human ancestry, dinosaurs. Laboratory involves examining the rocks and fossils that tell the story. Field trips to fossil-collecting sites and to Taughannock Gorge.

103 Geology in the Field
Fall. 3 credits. Limited to 35 students.
1 lec, 1 field trip or lab, 1 rec.
A. L. Bloom.
The subject matter of Geol 101, taught as much as possible by field trips on campus and in the vicinity, on foot and by bus. Weekly field trips until November introduce most of the major topics of the course, supplemented by lectures, recitations, and labs later in the term.

104 Introduction to Oceanography
Spring. 3 credits.
2 lecs, 1 lab. W. M. White.
The oceans remain one of the last frontiers, yet they affect our everyday lives in many subtle ways. A survey of what is known of the physics, chemistry, geology, and biology of the oceans, intended for both science and non-science majors. Topics include: sea-floor spreading and plate tectonics; geology and biology of mid-ocean ridges; biological and geological controls on the chemisry of seawater; ocean currents and circulation; the oceans and climate, including El Niño, the greenhouse effect, and the Ice Ages; ecology of open ocean, ocean bottom, and near-shore communities; coastal processes; marine pollution and waste disposal; mineral and biological resources of the sea; Law of the Sea. At the level of *Scientific American.*

107 Frontiers of Geology I
Fall. 1 credit. May be taken concurrently with or after Geol 101, 102, 103, 104, 111, 201, or 202.
1 lec. J. L. Cisne and staff.
What is it like to get beyond the textbooks and standard introductory courses and do geological research? What are some of today's big questions, and how are they being answered? This course is an opportunity for beginning geology students to hear answers to these questions from a different Cornell researcher every week. Lectures are geared to the fall introductory geology courses.

108 Frontiers of Geology II
Spring. 1 credit. May be taken concurrently with or after Geol 101, 102, 103, 104, 111, 201, or 202.
1 lec. J. L.Cisne and staff.
Like Geol 107, but geared to the spring introductory geology courses.

111 To Know the Earth
Fall. 3 credits.
2 lecs, 1 lab, and field trips. J. E. Oliver.
Acquaints the non-scientist with the earth. Geology as an intellectual challenge, a provider of resources, an environment, a danger, a base for culture, and a science among sciences. The story behind landscapes, mountains, earthquakes, volcanoes, oceans, gold, petroleum, and icecaps. The record of the past, the context of the present, the forecast for the future.

201 Introduction to the Physics and Chemistry of the Earth (also Engr 201)
Spring. 3 credits. Prerequisites: Mathematics 191, Physics 112, and Chemistry 207.
2 lecs; 1 rec, lab, or field trip.
L. M. Cathles.
For description see Engineering Common Courses.

202 Environmental Geology
Spring. 3 credits.
2 lecs; 1 rec, lab, or field trip. D. E. Karig.
In-depth introduction to geologic processes that affect or are affected by human society, including stream behavior and floods, earthquakes, land stability and mass-wasting, and volcanic hazards. This material provides an application of geology to engineering, natural resources, and land-use planning. Local examples are discussed and visited on short field trips. The course can be taken as an introduction to geology, but also serves as a continuation of Geol 101.

210 Introduction to Field Methods in Geological Sciences
Fall. 2 credits. Prerequisite: Geol 101 or coregistration. Weekly field sessions. A weekend field trip.
D. E. Karig.
An introduction to the methods by which rocks are used as a geological database. Students are introduced to the field methods used in the construction of geologic maps and cross sections and to systematic description of stratigraphic sections. Field and laboratory sessions are held on Saturday mornings until Thanksgiving; during most of these weeks there is also one additional lecture. One weekend is devoted to a field trip to eastern New York.

212 Special January Field Trip
Fall. 1 credit. Prerequisites: Geol 101 or 201 or equivalent, and permission of instructor. Travel and subsistence expenses to be announced.
1 lec, field trip. Staff.
A trip of one week to ten days during January intersession in an area of interesting geology in the lower latitudes. Interested students should contact the instructor during the early part of the fall semester.

213 Marine and Coastal Geology
Summer. 2 credits. Prerequisites: an introductory course in geology or permission of instructor.
A special one-week course offered at Cornell's Shoals Marine Laboratory (SML), on an island near Portsmouth, New Hampshire. For more details and an application, consult the SML office, G14 Stimson Hall. Estimated cost (including tuition, room, board, and ferry transportation) is $600.

214 Western Adirondack Field Course
Spring, one week at the end of the semester. 1 credit. Prerequisite: Geol 101 or 102 or equivalent. Students should be prepared for overnight camping and share in the cost of camp meals.
W. A. Bassett.
Field mapping methods, mineral and rock identification, examination of Precambrian metamorphic rocks and lower Paleozoic sediments, talc and zinc mines.

Junior, Senior, and Graduate Courses

Of the following, the core courses Geol 326, 355, 356, 375, and 388 may be taken by those who have successfully completed Geol 201 or the equivalent or who can demonstrate to the instructor that they have adequate preparation in mathematics, physics, chemistry, biology, or engineering.

326 Structural Geology
Fall. 4 credits. Prerequisite: Geol 101 or 201, or permission of instructor.
3 lecs, 1 lab, field trips. Staff.
Nature and origin of deformed rocks at microscopic to macroscopic scales, with emphasis on structural geometry and kinematics.

355 Mineralogy
Fall. 4 credits. Prerequisite: Geol 101 or 201 and Chem 207 or permission of instructor.
1 lec, 1 lab; assigned problems and readings. W. A. Bassett.
Examination of minerals by hand-specimen properties and optical microscopy. Geological setting, classification, crystal structures, phase relations, chemical properties, and physical properties of minerals are studied. X-ray diffraction is introduced.

356 Petrology and Geochemistry
Spring. 4 credits. Prerequisite: Geol 355.
2 lecs, 2 labs, 1 field trip; assigned problems and readings. R. W. Kay.
Principles of phase equilibrium as applied to igneous and metamorphic systems. Description, classification, chemistry, origin, regional distribution, and dating of igneous and metamorphic rocks. Geochemical distribution of trace elements and isotopes in igneous and metamorphic systems. The petrological evolution of the planets.

375 Sedimentology and Stratigraphy
Fall. 4 credits. Recommended: Geol 102 or 201.
3 lecs, 1 lab, field trips. J. L. Cisne.
Formation of sedimentary rocks. Depositional processes. Depositional environments and their recognition in the stratigraphic record. Correlation of strata in relation to time and environment. Seismic stratigraphy. Geological age determination. Reconstruction of paleogeography and interpretation of earth history from stratigraphic evidence.

388 Geophysics and Geotectonics
Spring. 4 credits. Prerequisites: Mathematics 192 and Physics 208, 213, or equivalent.
3 lecs, 1 lab. B. L. Isacks.
Global tectonics and the deep structure of the solid earth as revealed by investigations of earthquakes, earthquake waves, the earth's gravitational and magnetic fields, and heat flow.

401 Field Geology
Summer. 4 credits. Prerequisites: Geol 210, 214, and 326, or permission of instructor. Four weeks at research sites in the western United States or Canada. Fee, approximately $1,200.
Staff.
Field mapping techniques in igneous, metamorphic, and sedimentary rock, using topographic maps and air photos. The structural geology, petrology, geomorphology, and sedimentology of selected areas in the Rocky Mountains will be included. An independent project and report is done during the last week.

412 Experiments and Techniques in Earth Sciences
Spring. 2 credits. Prerequisites: Physics 213 and Mathematics 192 or equivalents, or permission of instructor.
S. Kaufman.
Laboratory and field experiments chosen in accordance with students' interests. Familiarization with instruments and techniques used in earth sciences. Independent work is stressed.

[424 Petroleum Geology
Fall. 3 credits. Recommended: Geol 326. Offered alternate years. Not offered 1990–91.
2 lecs, 1 lab. W. B. Travers.
Introduction to hydrocarbon exploration and development. Exploration techniques, including geologic use of well logs, fluid pressures, seismic-reflection methods, gravity, and magnetic measurements to map subsurface structures and stratigraphy. Petroleum origin and migration. Dispersal systems and depositional patterns of petroleum reservoirs. Economics of exploration, leasing, drilling and production, and estimates of petroleum reserves, including tar sands and oil shales.]

[431 The Earth's Crust: Structure, Composition, and Evolution
Fall. 3 credits. Prerequisites: Geol 356 and 388. Offered alternate years. Not offered 1990–91.
3 lecs. L. D. Brown.
Structure and composition of the crust from geophysical observations, analysis of xenoliths, and extrapolation of petrological laboratory data. Radioisotopic considerations. The nature of the crust-mantle boundary. Thermal and rheological structure of the crust. Oceanic versus continental crust. Origin and evolution of oceanic and continental crust.]

[432 Digital Processing and Analysis of Geophysical Data
Spring. 3 credits. Prerequisite: Geol 487 or equivalent. Offered alternate years. Not offered 1990–91.
3 lecs. L. D. Brown.
Sampling theory. Fourier, Laplace, and Z-transform techniques. Spectral analysis. Temporal and spatial filtering. Seismic processing theory: signal enhancement and imaging.]

433 Exploration Seismology I: Data Acquisition and Processing
Fall. 3 credits. Prerequisite or corequisite: Geol 487 or equivalent. Offered alternate years.
3 lecs. L. D. Brown.
Planning seismic reflection and refraction surveys. Array design. Source characteristics and ground coupling. Land and marine operations. 2-D and 3-D surveys. Convolutional seismic model. Applied seismic processing: FK filtering, deconvolution, velocity analysis, stacking, migration, display. True amplitude processing.

434 Exploration Seismology II: Analysis and Interpretation
Spring. 3 credits. Prerequisite: Geol 487 or equivalent. Offered alternate years.
3 lecs. L. D. Brown.
Techniques for inferring geologic structure and lithology from multichannel seismic reflection data and crustal refraction data. Migration. Velocity and amplitude interpretation, correlation criteria, resolution wave-form analysis, seismic structure, and stratigraphy. Seismic modeling. 3-D and VSP. Attribute and tau-p analysis.

441 Geomorphology
Fall. 3 credits. Prerequisite: Geol 102 or 201, or permission of instructor.
2 lecs, 1 lab. A. L. Bloom.
Systematic analysis of landforms constructed by tectonic and volcanic processes and their subsequent progressive destruction by climate-controlled erosional processes.

[442 Glacial and Quaternary Geology
Spring. 3 credits. Prerequisite: Geol 441 or permission of instructor. Offered alternate years. Not offered 1990–91.
2 lecs, 1 lab; several field trips.
A. L. Bloom.
Glacial processes and deposits and the chronology of the Quaternary Period.]

445 Geohydrology (also Ag Eng 471 and C&EE 431)
Fall. 3 credits. Prerequisites: Mathematics 294 and Engr 202.
3 lecs. A. L. Bloom, L. M. Cathles, J.-Y. Parlange, T. S. Steenhuis.
Intermediate-level study of aquifer geology, groundwater flow, and related design factors. Includes description and properties of natural aquifers, groundwater hydraulics, soil water, and solute transport.

[452 X-ray Diffraction Techniques
Spring. 3 credits. Prerequisites: Geol 355 or permission of instructor. Offered alternate years. Not offered 1990–91.
1 lec, 2 labs. W. A. Bassett and staff.
Automated X-ray diffractometer, Debye-Scherrer, real-time Laue, high-temperature diffraction, high-pressure diffraction, and pole-figure analysis. Applications in materials science and geological sciences. Labs will be held in the new Materials Science X-Ray Facility.]

453 Modern Petrology
Fall. 3 credits. Prerequisite: Geol 356. Offered alternate years.
2–1/2 lecs, 1/2 lab. R. W. Kay.
Magmas and metamorphism in the context of plate tectonics. Major and trace element chemistry and phase petrology as monitors of the creation and modification of igneous rocks. Temperature and stress in the crust and mantle and their influence on reaction rates and textures of metamorphic rocks. Application of experimental studies to natural systems. Reading from the literature and petrographic examination of pertinent examples.

454 Advanced Mineralogy
Spring. 3 credits. Prerequisite: Geol 355 or permission of instructor. Offered alternate years.
2 lecs, 1 lab. W. A. Bassett.
Crystallography and crystal chemistry of minerals and the methods of their study. X-ray diffraction, optical methods, computer simulation of crystal structures. Emphasis on effects of high pressures and temperatures with implications for understanding of Earth's interior.

456 Geochemistry
Spring. 3 credits. Prerequisites: Chemistry 207 or 211, Geol 101 or 201 or equivalent, and Mathematics 112 or 192. Recommended: Geol 355 and 356.
3 lecs. W. M. White.
Thermodynamics applied to geology. Principles of trace-element and isotope geochemistry and their application to the study of igneous and metaporphic rocks. Overview of nucleosynthesis, cosmochemistry, and formation and chemical evolution of the earth. Introduction to the chemistry of the oceans and marine sediments.

[474 Modern Depositional Systems
Spring. 3 credits. Prerequisite: Geol 375 or permission of instructor. Offered alternate years. Not offered 1990–91.
3 lecs. T. E. Jordan.
Compositions, textures, sedimentary structures, and facies variations of sediments in modern depositional environments. Clastic and carbonate environments; fluvial, alluvial-fan, delta, intertidal, submarine-fan, carbonate-bank, and sabkha systems. Required field trip during spring recess to region of modern examples and/or rock sequences demonstrating ancient examples.]

[476 Sedimentary Basins: Tectonics and Mechanics
Spring. 3 credits. Prerequisite: Geol 375 or permission of instructor. Offered alternate years. Not offered 1990–91.
3 lecs. T. E. Jordan.
Subsidence of sedimentary basins from the point of view of plate tectonics and geomechanics. Interactions of subsidence, sediment supply, and environmental characteristics in development of stratigraphic sequences. Framework of active-margin, passive-margin, and cratonic basins; and stratigraphy. Topics include geophysical and stratigraphic modeling, and sequence stratigraphy. Modern and ancient examples.]

[478 Advanced Stratigraphy
Spring. 3 credits. Prerequisite: Geol 375 or permission of instructor. Offered alternate years. Not offered 1990–91.
2 lecs, 1 lab, possible spring break field trip. T. E. Jordan.
Survey of modern improvements on traditional methods of study of ages and of genetic relations among sedimentary rocks, emphasizing 3-D relationships. Techniques and applications of sequence stratigraphy at scales ranging from beds to entire basins. Physical correlation, dating techniques, and time resolution in sedimentary rocks. Physical controls on the stratigraphic record and numerical modeling.]

[479 Paleobiology (also Bio Sci 479)
Fall. 3 credits. Prerequisites: Biological Sciences 101–102 and 103–104 or equivalent, and either Geol 375, Biological Sciences 272–274, Biological Sciences 373, or permission of instructor. Offered alternate years. Not offered 1990–91.
3 lecs. J. L. Cisne and staff.
Survey of the major groups of organisms and their evolutionary histories. Intended to fill out the biological backgrounds of geology students and the geological backgrounds of biology students concerning the nature and significance of the fossil record for their respective studies.]

487 Geophysical Prospecting
Fall. 3 credits. Prerequisites: Physics 213 and Mathematics 192 or equivalents, or permission of instructor.
2 lecs. S. Kaufman.
Physical principles, instrumentation, operational procedures, and interpretation techniques in geophysical exploration for oil, gas, and minerals. Seismic reflection, seismic refraction, gravity, and magnetic and electrical methods of exploration.

[489 Earthquakes and Tectonics
Fall. 3 credits. Prerequisites: Geol 101 or 201, Mathematics 192, Physics 213, or permission of instructor. Offered alternate years. Not offered 1990–91.
3 lecs. B. L. Isacks.
The mechanisms of earthquakes revealed by seismic-wave radiation and by near-source studies of faulting and surface deformation; relationships to regional tectonics; earthquake hazard and prediction.]

490 Honors Thesis (B.A. degree candidates)
Fall, spring. 2 credits.
Staff.
Thesis proposal to be discussed with director of undergraduate studies during the junior year. Participation requires acceptance of a thesis proposal by the faculty committee.

491–492 Undergraduate Research
Fall, spring. 1 credit.
Staff (D. E. Karig and A. L. Bloom, coordinators).
An introduction to the techniques and philosophy of research in the earth sciences and an opportunity for undergraduates to participate in current staff research projects. Topics chosen in consultation with, and guided by, a staff member. A short written report is required, and outstanding projects are prepared for publication.

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.
L. M. Cathles.
The project may address one of many aspects of groundwater flow and contamination, and must involve a significant geological component and lead to concrete recommendations or conclusions of an engineering nature. Results are presented in GS 501, Geohydrology Design Project Seminar.

501 Geohydrology Design Project Seminar
Fall, spring. 1 credit. Required for the M.Eng. degree, geohydrology option.
1 rec., hours to be arranged.
L. M. Cathles.
In fall, the weekly seminar provides a forum for discussion of courses and development of design projects (see GS 500). In spring, it provides an opportunity to present and discuss design projects.

502 Case Histories in Groundwater Analysis
Spring. 4 credits.
L. M. Cathles, A. L. Bloom.
Groundwater flow in a specific area, such as a proposed nuclear-waste disposal site, is analyzed in depth. Geological and resource data on the area are presented early in the course. For the remainder of the semester, the material is analyzed by students working as an engineering analysis team. Each student makes a weekly progress report and writes part of a final report, whose results are presented in a half-day seminar at end of term.

621 Marine Tectonics
Fall. 3 credits. Prerequisites: Geol 326 and a course in geophysics. Offered alternate years.
3 lecs. D. E. Karig.
Study of geophysical and geological characteristics of the earth's crust beneath the oceans. Emphasis on recent geologic data concerning plate margins in the oceans; island-arc systems, spreading systems, and transforms. Techniques for determining instantaneous and finite plate rotations. Lectures and reviews of recent papers. Term project and paper required.

[622 Advanced Structural Geology I
Spring. 3 credits. Prerequisites: Geol 326 and permission of instructor. Offered alternate years. Not offered 1990–91.
2 lecs, 1 lab, possible weekend field trips.
D. E. Karig, R. W. Allmendinger.
Stress-strain theory and application. Advanced techniques of structural analysis. Topics include finite and incremental strain measurement; microstructure, preferred orientation, and TEM analysis; pressure solution and cleavage development; and experimental deformation. Applications to deformation of unconsolidated sediments, brittle and brittle-ductile deformation of supracrustal strata, and ductile deformation of high-grade metamorphic rocks. Kinematic analysis of shear zones and folds in these regimes.]

[624 Advanced Structural Geology II
Spring. 3 credits. Prerequisites: Geol 326 and permission of instructor. Offered alternate years. Not offered 1990–91.
2 lecs, 1 lab, spring-recess trip.
R. W. Allmendinger, D. E. Karig.
Geometry, kinematics, and mechanics of structural provinces. Concentration on thrust belts, rift provinces, or strike-slip provinces. Techniques of balanced cross sections.]

625 Tectonic History of Western North America from Craton to Terrances
Fall. 2 credits. Open to seniors and graduate students. Offered alternate years.
Lecture, term paper, quizzes, no final.
W. B. Travers.
Seminar on current research on the sequence, style, and mechanics of deformation, with emphasis on growth of the continent in the western United States and southern Canada.

628 Geology of Orogenic Belts
Spring. 4 credits. Prerequisite: permission of instructor.
T R 10:10–12:05. J. M. Bird.
A seminar course in which students study specific geologic topics of an orogenic belt selected for study during the term. The course is intended to complement Geol 781.

635 Advanced Geophysics I: Quantitative Geodynamics
Fall. 3 credits. Prerequisite: Geol 388.
3 lecs. D. L. Turcotte.
Stress and strain, elasticity and flexure, heat transfer, gravity, fluid mechanics, rock rheology, faulting, and flow in porous media.

637 Advanced Geophysics II: Fundamentals of Mantle Convection
Spring. 3 credits. Prerequisite: Geol 388.
3 lecs. D. L. Turcotte.
Fractals and chaos, structure of the mantle, material properties, heat sources, basic equations, linear stability analysis, approximate solutions, numerical solutions, plumes, laboratory experiments, geochemistry, early thermal history, terrestrial planets and satellites.

655 Isotope Geochemistry
Fall. 3 credits. Open to undergraduates. Prerequisite: Geol 356 or permission of instructor. Offered alternate years.
2 lecs. W. M. White.
Nucleosynthetic processes and the isotopic abundance of the elements. Dating by Pb, Ar, Sr, and Nd isotope variations. Theories of crustal and mantle evolution. Pleistocene chronology using U-series and 14C dating. Time constants for geochemical cycles. The use of O and H isotopes as tracers in the earth's hydrosphere, and hydrothermal circulation systems.

681 Geotectonics
Fall. 4 credits. Prerequisite: permission of instructor.
2 lecs. J. M. Bird.
Theories of orogeny; ocean and continent evolution. Kinematics of lithosphere plates. Rock-time assemblages of modern oceans and continental margins, and analogs in ancient orogenic belts. Time-space reconstructions of specific regions. Problems of dynamic mechanisms—corollaries and evidence from crustal features.

687 Seismology
Fall. 3 credits. Prerequisite: T&AM 611 or equivalent. Offered alternate years.
3 lec-recs. B. L. Isacks.
Generation and propagation of elastic waves in the earth. Derivation of the structure of the earth and the mechanism of earthquakes from seismological observations.

695 Computer Methods in Geological Sciences
L. D. Brown, B. L. Isacks.
This course is intended to familiarize students with the growing importance of computers in geological and geophysical research. Students will be required to develop, debug, implement, and document a program relevant to current research in the Department of Geological Sciences. Available facilities include the department's VAX workstations, MEGASEIS seismic computer, Landmark Interpretation Workstation, IIS image processor, and numerous graphics and I/O peripherals. The Cornell National Supercomputer Facility may also be used.

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.

721 Tectonic and Stratigraphic Evolution of Sedimentary Basins
W. B. Travers.

722 Advanced Topics in Structural Geology
R. W. Allmendinger.

725 Rock and Sediment Deformation
D. E. Karig.

731 Plate Tectonics and Geology
J. M. Bird.

741 Advanced Geomorphology Topics
A. L. Bloom.

751 Petrology and Geochemistry
R. W. Kay.

753 Mineralogy and Crystallography, X-Ray Diffraction, Microscopy, High-Pressure–Temperature Experiments
W. A. Bassett.

755 Advanced Topics in Petrology and Tectonics
J. M. Bird, W. A. Bassett.

757 Current Research in Petrology
R. W. Kay.

762 Advanced Topics in Petroleum Exploration
W. B. Travers.

771 Advanced Topics in Sedimentology and Stratigraphy
T. E. Jordan.

773 Paleobiology
J. L. Cisne.

780 Seismic Record Reading
M. Barazangi, B. L. Isacks.

781 Geophysics, Exploration Seismology
L. D. Brown.

783 Advanced Topics in Seismology
B. L. Isacks.

785 Exploration Seismology, Gravity, Magnetics
S. Kaufman.

788 Geophysics, Seismology, and Geotectonics
J. E. Oliver.

789 Research on Seismic-Reflection Profiling of the Continental Crust
J. E. Oliver, L. D. Brown, S. Kaufman.

793 Andes Seminar
B. L. Isacks, T. E. Jordan, A. L. Bloom, R. W. Allmendinger.

796 Geochemistry of the Solid Earth
Fall.
W. M. White.

797 Fluid-Rock Interactions
L. M. Cathles.

799 Contemporary Issues in Groundwater Hydrology
Spring.
L. M. Cathles.

MATERIALS SCIENCE AND ENGINEERING

Undergraduate Courses

201 Elements of Materials Science and Engineering (also Engr 111)
Fall. 3 credits.
For description see Engineering Common Courses.

261 Introduction to Mechanical Properties of Materials (also Engr 261)
Fall, spring. 3 credits.
2 lecs, 1 rec or lab.
For description see Engineering Common Courses.

262 Introduction to Electrical Properties of Materials (also Engr 262)
Spring. 3 credits.
2 lecs, 1 rec or lab.
For description see Engineering Common Courses.

285 Art, Isotopes, and Analysis (also Engr 285, Physics 200, Archaeology 285, English 285, and Art 372)
Spring. 3 credits.
3 lecs. J. W. Mayer, S. Taft, D. Eddy.
For description see Engineering Common Courses.

331 Structural Characterization of Materials
Fall. 4 credits.
3 lecs, 1 lab.
Crystal structures and crystal defects, stereographic projection methods. Techniques for materials analysis: X-ray and electron diffraction, optical and electron microscopy. Design of experimental systems for the structural characterization of materials.

332 Electrical and Magnetic Properties of Materials
Spring. 3 credits. Prerequisite: MSE 331 or permission of instructor.
3 lecs.
Electrical and magnetic properties of metals and semiconductors as affected by microstructure. Design of semiconductor properties by doping. Carrier drift, diffusion, and recombination. Depletion layers in p-n junctions. Design of semiconductor devices. Principles and design of ferromagnetic materials for transformers, permanent magnets, and bubble memories. Fundamentals and design of superconducting materials for high-field magnets and Josephson junctions.

333 Research Involvement I
Fall. 3 credits. Prerequisite: approval of department.
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. Typical projects have involved hot isostatic compaction, sputter etching, and mechanical testing of polymer films.

334 Research Involvement II
Spring. 3 credits. Prerequisite: approval of department.
May be a continuation of MS&E 333 or a one-term affiliation with a research group.

335 Thermodynamics of Condensed Systems
Fall. 4 credits.
3 lecs.
The three laws of thermodynamics are introduced as a basis for understanding phase equilibria, heterogeneous reactions, solutions, electrochemical processes, surfaces, and defects. One-third of the course involves examples of design and control of materials processing and microstructure.

336 Kinetics, Diffusion, and Phase Transformations
Spring. 3 credits. Prerequisite: MS&E 335 or permission of instructor.
3 lecs.
Introduction of absolute rate theory, atomic motion, and diffusion. Applications and design involving nucleation and growth of new phases in vapors, liquids, and solids; solidification, crystal growth, oxidation and corrosion, radiation damage, recrystallization, gas-metal reactions, and thermomechanical processing to produce desired microstructures and properties.

345 Materials and Manufacturing Processes (also M&AE 312)
Spring. 3 credits. Prerequisite: T&AM 202 or permission of instructor.
2 lecs, 1 lab.
For description see M&AE 312.

435–436 Senior Thesis I & II
435, fall; 436, spring. 4 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.

441 Microprocessing of Materials
Fall. 3 credits.
3 lecs, occasional lab.
Materials and processing steps involved in the production of large-scale integrated circuits. Design of processes to give a specific device, e.g., a MOSFET is described, not circuit design. Emphasis is on silicon devices, with mention of Gallium Arsenide. All steps in fabrication of circuits are considered, starting with purification of silicon, single-crystal growth, zone refining, and wager slicing. Thin-film growth by epitaxy, by chemical or physical vapor deposition, or by thermal oxidation of silicon to SiO2. Doping of layers by diffusion and by ion implantation. Principles and practice of lithography; comparison of near and far UV, electrons and X-rays for resolution, output, and cost. Photoresists. Wet and dry etching. Characterization and testing, yield. Electromigration and other device failure modes.

442 Macroprocessing (also M&AE 512)
Spring. 3 credits.
3 lecs.
Deformation processing of materials, including superplastic forming, sheet-metal forming, massive forming, and powder processing. Time, temperature, and strain-rate effects in warm-forming and hot-forming. Characterization of powder-compaction mechanisms and their use in process design. Forming-limit diagrams. Development of microstructure-based criteria for fracture in large deformations. Optimization and design of forming processes. Development of constitutive equations for superplastic flow. Design of a superplastic forming process starting from basic mechanisms. The course includes a comprehensive experimental project in which the constitutive equations for superplastic flow are measured and computer-aided techniques are used to design a superplastic forming process. The forming experiment is carried out, and the results are compared with the predictions from the numerical analysis.

443–444 Senior Materials Laboratory
443, fall; 444, spring. 3 credits.
Projects are available in plasticity of metals and ceramics, mechanical and chemical processing, phase transformations, electrical and ionic conductivity, analysis of defects by electron microscopy, sintering, crystal growth, thin-film fabrication, electronic materials, etc. Emphasis is placed on design of experimental equipment for analysis and evaluation of a material's properties and performance in terms of its processing history and microstructure.

445 Mechanical Properties of Materials
Fall. 3 credits. Prerequisites: MS&E 331 and 336, or permission of instructor.
3 lecs.
Relation between stress, strain, and the concept of equivalent stresses and strains; failure criteria for metals, polymers, and ceramics. Applications of fracture mechanics to fail-safe design. Analysis of important mechanical properties such as plastic flow, creep, fatigue, fracture toughness, and rupture and their variation with temperature in terms of the interaction of the microstructure with lattice defects. Application of these principles to the design of improved materials.

447 Materials Design Concepts I
Fall. 2 credits.
Speakers from industry and other institutions will give case studies of design problems. Students will write a proposal for a design-study project, which will be approved by the instructor. At the level of *Engineering Design*, by Dieter.

448 Materials Design Concepts II
Spring. 2 credits. Prerequisite: MS&E 447.
Each student is expected to complete an extensive design-study project and give a thirty-minute video-taped talk on a materials-design problem that includes a discussion of economic factors as well as the design of processes and the selection of materials. At the level of *Engineering Design*, by Dieter.

449 Introduction to Ceramics
Fall. 3 credits. Prerequisite: MS&E 331 or permission of instructor.
3 lecs.
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.

450 Physical Metallurgy
Spring. 3 credits.
The service and design requirements of engineering alloys and their testing and characterization. The properties of important alloy systems. The selection and design of alloys for various engineering requirements, such as ASME design codes.

452 Properties of Solid Polymers
Spring. 3 credits. Prerequisite: Engr 261 or permission of instructor.
3 lecs.
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.

454 Processing of Glass, Ceramic, and Glass-Ceramic Materials
Spring. 3 credits. Offered alternate years.
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 two scientists from the research and development laboratory of Corning Glass Works.

455 Analysis of Manufacturing Processes (also M&AE 512)
Spring. 3 credits. Prerequisite: M&AE 312.
3 recs.
For description see M&AE 512.

459 Physics of Modern Materials Analysis
Fall. 3 credits.
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 necessary for understanding techniques of modern materials analysis, such as Auger electron spectroscopy, ion scattering, and secondary ion mass spectroscopy. Design of experiments for near-surface analysis.

463 Principles of Electronic Packaging
Fall. 3 credits.
Design and materials 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.

Graduate-Level Professional Courses

510 Optical Methods and Materials
Fall. 3 credits.
Principles of geometric and Gaussian optics, instrumentation required for optical experiments, and methods in optical spectroscopy. Fundamental aspects of the interaction between optical waves and crystalline solids. Materials aspects of optical devices such as optical films and coatings, light-modulation devices, displays, lasers and detectors, optical waveguides, electro-optic devices, optical recording, and applications of high-intensity light beams.

512 Chemical Thermodynamics of Materials
Fall. 3 credits.
Thermodynamic principles. Chemical potentials, fugacities, and activities. Closed and open systems. Stability of single- and multicomponent systems. Reactions. Binary and multi-component systems and phase diagrams. Compounds. Surfaces, surface tension, and adsorption. Special topics such as electrochemistry, corrosion, and chemical-vapor deposition.

514 Chemical Processing of Ceramics
Spring. 3 credits.
Ultrastructure processing of ceramics, glasses, and composites. Chemical approaches in designing and controlling the surfaces and interfaces of materials, devices, and structures at the molecular level. Topics: organometallic routes to ceramics; sol-gel processing, chemical vapor deposition, and pyrolysis techniques; design, synthesis, and chemical properties of inorganic/organometallic precursors; preparation, surface chemistry, and micromechanics of controlled powders; characterization of chemically processed ceramics; application of sol-gel derived materials; advanced structural ceramics.

516 Thin-Film Materials Science
Fall. 3 credits.
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.

518 Introduction to Electron Microscopy
Spring. 3 credits. Prerequisite: MS&E 331 or permission of instructor.
3 lecs.
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 EDS, WDS, and EELS. X-ray imaging. Overview of specimen preparation and in-situ microscopy.

520 Practical Electron Microscopy
Spring. 3 credits. Corequisite: MS&E 518–520. Limited to 12 students. A fee will be charged for instrument usage.
Lab.
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.

553–554 Special Project
553, fall; 554, spring. 6 credits each term.
Research on a specific problem in the materials area.

Graduate Core Courses

601 Thermodynamics of Materials
Fall. 3 credits.
Basic statistical thermodynamics. Partition function 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. Nucleation phenomena.

602 Elasticity and Physical Properties of Crystals
Fall. 3 credits.
Cartesian tensors, elastic stress and strain, constitutive relations between stress and strain, symmetry of crystals, generalized tensor representation of elasticity and other reversible and irreversible properties of crystals; mathematical theory of infinitesimal elasticity with applications, including wave propagation and stress fields of dislocations; mathematical theory of yield stress and plasticity; origin of elastic behavior. At the level of Physical Properties of Crystals, by Nye.

603 Structural Defects in Solids
Spring. 3 credits. Prerequisites: MS&E 601 and 602, or equivalent.
Binding energies in perfect crystals. Structure and energetics of point, line, and planar defects in crystalline materials, including metals, ionic solids, covalent solids, and polymers. Interactions between defects. Bonding and random packing in amorphous materials. Observation of defects in crystalline materials. Structural analysis of amorphous materials.

604 Kinetics of Solid-State Reactions
Spring. 3 credits.
Point defects (thermal disorder, component-activity-dependent disorder, influence of dopants, different kinds of associates, Coulomb interaction between point defects), dislocations, interfaces, transport in solids (definition and different kinds of diffusion coefficients, reference frames, electrical conduction, diffusion mechanisms, atomic theory of transport, correlation effects, phenomenological theory of transport including some aspects of thermodynamics of irreversible processes), point-defect relaxation (migration controlled, phase-boundary-reaction controlled), interdiffusion, solid-state reactions involving compound formation, behavior of materials in potential gradients, selected solid-state processes (sintering, solid-state galvanic cells, etc.).

605 Plastic Flow and Fracture of Materials
Fall. 3 credits.
R. Raj.
Topics in the mechanical behavior of materials from a fundamental standpoint. Atomistic aspects of elastic properties, plastic flow in single crystals and polycrystals, rate-dependent deformation at elevated temperature, mapping of various mechanisms of plastic flow over a wide range of temperature, shear stress and grain size, and superplastic deformation. Fracture is discussed from a thermodynamic as well as an atomistic standpoint. Fracture criteria are developed in terms of crack-tip processes. Cleavage, ductile brittle transition, and intergranular cavitation failure at high temperatures. Emphasis on micromechanical modeling of mechanical behavior. A materials-science approach to modeling that combines concepts from continuum mechanics, thermodynamics, kinetics, and atomic structure.

Related Course in Another Department

Introductory Solid-State Physics (Physics 454)

Further Graduate Courses

610 Principles of Diffraction (also A&EP 711)
Fall. 3 credits. Offered alternate years.
For description see A&EP 711.

612 Phase Transformations
3 credits. Prerequisites: MS&E 601 and 604, or equivalent preparation.
Compositional and structural transitions in condensed systems, including spinoidal decomposition, cellular transformations, and diffusionless transformations; clustering and ordering in solid solutions; radiation-induced precipitation; condensation and evaporation phenomena; order-disorder transformations; transitions in magnetic, ferroelectric, and superconducting materials; phase equilibria and transitions in surface and grain-boundary layers. Phase transformations in metallic, ceramic, semiconducting, and polymeric systems. Thermodynamic, statistical thermodynamic, structural, and kinetic aspects of the transitions. Modern methods of observation. At the level of *The Theory of Transformations in Metals and Alloys*, by Christian; *Critical Phenomena in Alloys, Magnets and Superconductors*, edited by Mills, Ascher, and Jaffee; and current review articles.

616 Electrical and Magnetic Properties of Materials
3 credits. Prerequisite: Physics 454 or equivalent.
Electronic transport properties of metals and semiconductors, semiconductor devices, optical and dielectric properties of insulators and semiconductors, laser materials, dielectric breakdown, structural aspects of superconducting materials, ferromagnetism, and magnetic materials. At the level of *Physics of Semiconductor Devices*, by Sze; *Ferromagnetism*, by Bozworth; and current review articles.

618 Laser Processing of Materials
3 credits. Offered on demand.
Use of high-intensity lasers in the processing of materials to achieve unique microstructures and metastable phases. Topics: fundamentals of the interaction of E&M fields with metals, semiconductors and ceramics, transfer of energy between electronic and phonon systems, kinetics of rapid solidification, metastable phase transformations, microstructure of rapidly solidified materials, and current industrial applications.

620 Synthesis of Polymeric Materials
3 credits. Prerequisite: MS&E 452 or permission of instructor.
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. Topics will also include liquid crystalline polymers, polymers for photoresists, and adhesive-binder polymers. At the level of *Principles of Polymerization*, by Odian, and current literature.

622 X-Ray Diffraction in Materials Science
Fall. 3 credits. Offered on demand.
X-ray scattering and absorption by materials. Reciprocal lattice and brillouin zones. Space groups and various crystal structures. Diffraction from two- or three-dimensional periodic lattices and effect of thermal vibrations. Experimental techniques in X-ray diffraction with particular emphasis on the use of synchrotron sources. Determination of crystal structure by powder and single-crystal diffraction. Use of X-ray diffraction techniques in materials science in studying phase transformation and texture in materials. Diffraction from surface layers and amorphous materials.

671 Synthetic Polymer Chemistry (also Chem 671 and Chem E 675)
Fall. 3 credits. Offered on demand. Prerequisites: Chem 359–360 or equivalent, or permission of instructor. Recommended: M&SE 620.
For description see Chem E 675.

Specialty Courses

707 Solar Energy Materials
3 credits. Offered on demand.
3 lecs.
Photovoltaic energy conversion: (1) theory (on the level of Hovel); (2) the role of crystal defects and grain boundaries on the conversion efficiency, and schemes to passivate these defects; (3) current investigations in the DOE program to produce large quantities of solar-grade semiconducting Si; (4) theory and materials for amorphous silicon solar cells.

714 Advanced Transmission Electron Microscopy
Fall. 3 credits. Prerequisites: MS&E 518 and 520. Offered on demand.
3 lecs.
Kinematic and dynamic diffraction, dispersion surfaces, and Bloch waves. Anomalous absorption, Kikuchi band theory, and energy selected images. Contrast transfer function theory of phase constrast. Lattice imaging and image modeling. Calculation of multibeam defect images in theory and practice. Weak-beam images. Image processing. High-resolution SEM and STEM images. Convergent beam patterns.

716 Transition Metal Oxides (also Chem 716)
Fall. 3 credits. Offered on demand.
For description see Chem 716.

779 Special Studies in Materials Sciences
Fall, spring. Variable credit. Offered on demand.
Supervised studies of special topics in materials science.

798 Materials Science and Engineering Colloquium
Fall, spring. 1 credit each term. Credit limited to graduate students.
Lectures by visiting scientists, Cornell staff members, and graduate students on subjects of interest in materials sciences, especially in connection with new research.

799 Materials Science Research Seminars
Fall, spring. 2 credits each term. For graduate students involved in research projects.
Short presentations on research in progress by students and staff.

800 Research in Materials Science
Fall, spring. Credit to be arranged. Prerequisite: candidacy for Ph.D. in materials science.
Independent research in materials science under the guidance of a member of the staff.

801 Research in Materials Science
Fall, spring. Credit to be arranged. Prerequisite: candidacy for M.S. in materials science.
Independent research in materials science under the guidance of a member of the staff.

MECHANICAL AND AEROSPACE ENGINEERING

General and Required Courses

101 Naval Ship Systems (also Naval Science 102)
Spring. 3 credits. Limited to freshmen and sophomores. A free elective for engineering students.
M. Y. Louge.
An introduction to primary ship systems and their interrelation. Basic principles of ship construction. Stability, propulsion, control, internal communications, and other marine systems.

102 Drawing and Engineering Design (also Engr 102)
Fall, spring. 1 credit. Half-term course offered twice each semester. Enrollment limited to thirty students each half term. Recommended for students without previous mechanical drawing experience. S-U grades optional.
2 lecs, 1 lab.
For description see Engineering Common Courses.

117 Introduction to Mechanical Engineering (also Engr 117)
Fall. 3 credits.
2 lecs, 1 lab.
For description see Engineering Common Courses.

[119 Introduction to Manufacturing (also Engr 119 or OR & IE 119)
Spring. 3 credits. May not be offered 1990–91.
2 lecs, 1 lab.
For description see Engineering Common Courses.]

221 Thermodynamics (also Engr 221)
Fall, spring. 3 credits. Prerequisites: Mathematics 192 and Physics 112.
For description see Engineering Common Courses.

312 Fundamentals of Manufacturing Processes (also MS&E 345)
Spring; may be offered in Engineering Cooperative Program. 3 credits. Prerequisites: Engr 202 and 261, or permission of instructor.
2 lecs, 1 lab; evening exams and prelims may be given.
Yield criteria and plastic flow. Manufacturing processes for engineering materials, including metals, polymers, ceramics, and composites. Casting, forming, material removal, and joining processes.

323 Introductory Fluid Mechanics
Fall; usually offered in Engineering Cooperative Program. 4 credits. Prerequisites: Engr 202 and 203 and coregistration in 221, or permission of instructor.
4 lecs, evening prelims.
Statics, kinematics, potential flow, dynamics, momentum, and energy relations. Thermodynamics of compressible flow; dimensional analysis; real fluid phenomena, laminar and turbulent motion, boundary layer; lift and drag; supersonic flow and shock waves.

324 Heat Transfer
Spring; may be offered in Engineering Cooperative Program. 3 credits. Prerequisite: M&AE 323.
3 lecs, evening prelims.
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. Introduction to boiling and phase change.

325 Mechanical Design and Analysis
Fall; usually offered in Engineering Cooperative Program. 4 credits. Prerequisites: Engr 202 and 203.
3 lecs, 1 lab. Evening prelims may be given. Lab fee $25. S. E. Landsberger.
Application of the principles of mechanics and materials to problems of analysis and design of mechanical components and systems. A hands-on laboratory, the use of machine tools, and a final design project provide direct experience of creative design synthesis.

326 System Dynamics
Spring; may be offered in Engineering Cooperative Program. 4 credits. Prerequisite: M&AE 325, Mathematics 294, and Engr 210.
3 lecs, 1 lab, evening prelims.
Dynamic behavior of mechanical systems: modeling, analysis techniques, and applications; vibrations of single- and multi-degree-of-freedom systems; linear control systems, PDF control, stability analysis. Computer simulation and experimental studies of vibration and control systems.

427 Mechanical Engineering Laboratory
Fall. 4 credits. Prerequisites: M&AE 324 and 326.
1 lec, 2 labs.
Laboratory exercises in methods, techniques, and instrumentation used in mechanical engineering. Measurements of temperature, heat transfer, viscosity, drag, fluid-flow rate, effects of turbulence, shock wave phenomena, and engine performance. Weekly written assignments.

428 Engineering Design
Fall. 1 credit. Prerequisite: completion of six semesters in mechanical engineering or equivalent.
1 lec.
General principles of design, relevant to both the fluids, energy, and heat transfer stem and the mechanical systems and manufacturing stem of mechanical engineering.

Mechanical Systems and Design and Manufacturing

386 Automotive Engineering
Spring. 3 credits. Prerequisite: M&AE 325 or permission of instructor.
3 lecs.
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 vehicle may be considered.

389 Computer-Aided Design
Spring. 3 credits. Limited to juniors and seniors. Prerequisite: A course in programming. May be taken either before or in conjunction with a numerical-methods course. Fulfills computer applications requirement.
2 lecs, 1 sec of computational assignments at CADIF. D. L. Taylor.
A first course in CAD, introducing the use of software and computer methods in mechanical engineering. Topics include simulation, optimization, solution of field equations (finite elements, finite differences), least-square function approximation, geometry (space curves, splines, patches), and computer graphics.

417 Introduction to Robotics
Fall. 4 credits. Enrollment limited. Prerequisite: M&AE 326 or permission of instructor.
2 lecs, 1 lab.
Coordinate transformations for manipulator kinematics. Newton-Euler and Lagrangian developments of manipulator dynamics. Robot control schemes. Trajectory generation. Motion planning. Robot programming.

464 Design for Manufacture
Spring. 3 credits. Prerequisites: M&AE 312 and 428 and senior standing. Enrollment limited. Fulfills field design requirement.
Principles and methodologies for conceptual design; elimination procedures for selecting design alternatives; emphasis on design for manufacturability, quality, and cost considerations; team design projects from concept, analysis, and computer-aided drafting to manufacturing methods.

[465 Biomechanical Systems—Analysis and Design
Spring. 3 credits. Prerequisites: Engr 202 and 203. Not offered 1990–91.
2 lecs, 1 lab. D. L. Bartel.
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.]

478 Feedback Control Systems (also EE 471)
Fall. 4 credits. Prerequisite: EE 302, M&AE 326, or permission of instructor.
3 lecs. Open computer lab.
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, frequency response, and algebraic pole placement. Feedback architectures include PID, PDF, and lead/lag compensation. Applications include robotics, aerospace vehicles, and industrial processes. Computer-aided design laboratory examines modeling and control of a computer-simulated dynamic system.

486 Automotive Engineering Design
Spring. 3 credits. Prerequisite: M&AE 428 and senior standing. Fulfills field design requirement.
Selected topics in the analysis and design of vehicle components and vehicle systems. Emphasis is on automobiles, trucks, and related vehicles. Power plant, driveline, brakes, aerodynamics, suspension, and structure. Other vehicle types may be considered. Design project required.

489 Computer-Aided Design Project
Spring. 4 credits. Prerequisite: M&AE 428; limited to seniors in mechanical engineering. A project-oriented design course. Fulfills both field design and computer applications requirements.
2 lecs, 1 sec of computational assignments at CADIF.
Students will undertake a complete design of a complex system based on specification of performance and functionality. Evaluation will be on how well the design submitted satisfies objective. Topics vary annually, but typical topics include sailboat or aircraft design. Students will be expected to utilize CAD techniques and commercial software (drafting, solid modeling, finite-element analysis, simulation) as appropriate. Attendance in lectures and completion of interim projects will be mandatory.

512 Analysis of Materials Processing (also MS&E 442)
Spring. 3 credits. Prerequisite: M&AE 312.
3 lecs. P. Dawson, R. Raj.
Review of the basic principles governing the inelastic behavior of crystalline solids. Application of slab models, bound theorems, and slipline theory to problems of forging, extrusion, and rolling. Analysis of sheet-metal forming, including forming limits and springback. Discussion of defect initiation during forming processes.

514 Modeling, Metrology, and Machining
Fall. 3 credits, or 4 with laboratory. Prerequisites: Mathematics 294, Engr 100, and Engr 102.
3 lecs, 1 lab (optional). H. Voelcker.
Introduction to the main principles and current limitations of three technologies central to modern mechanical design and manufacturing: solid modeling, for defining "shapes" unambiguously; geometric tolerancing and dimensional metrology, for specifying and verifying variations in part geometry; and NC machining, for making parts under program control.

569 Mechanical and Aerospace Structures I: Applied Analysis of Stress and Deformation
Fall. 3 credits. Prerequisite: M&AE 325 or permission of instructor.
A study of advanced topics in the analysis of stress and deformation of elastic bodies, with applications to the analysis and design of mechanical and aerospace systems. Fundamentals are reviewed and applied to classical problems of solid and structural mechanics.

575 Microprocessor Applications
Fall. 3 credits. Enrollment limited; intended for graduate students with limited background in digital circuitry; open to undergraduates with permission of instructor. Prerequisite: background in basic laboratory electronics. Fulfills computer applications requirement.
2 lecs, 1 lab.
Introduction to digital circuitry, microprocessors, and microprocessor-based data acquisition and control systems. Basic concepts of data representation, microprocessor and microcomputer structure, parallel and serial input/output, analog-to-digital conversion, and hardware and software requirements for interfacing. Emphasis on applications of the 8088 microprocessor and assembly language programming. Independent laboratory work on several applications projects, including the process control procedures.

577 Mechanical Vibrations
Fall. 3 credits. Open to qualified undergraduates. Prerequisite: M&AE 326 or equivalent.
2 lecs, 1 lab (occasional).
Vibration phenomena in single– and multiple–degree-of-freedom linear and nonlinear systems, with emphasis on engineering problems involving analysis and design.

578 Feedback Control Systems Design and Implementation
Spring. 3 credits. Open to qualified undergraduates. Prerequisite: M&AE 478 or EE 471, or permission of instructor.
1 lec, 2 labs. M. L. Psiaki.
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 covered briefly. 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.

[589 Computer-aided Research, Design, and Development
Fall. 3 credits. Prerequisite: M&AE 489 or equivalent. Not offered 1990–91.
2 lecs, computational assignments at CADIF. D. L. Taylor.
Introduction to a wide range of topics and programming techniques that are useful in the development of engineering models for computer analysis. Emphasis on data structure and integration of existing packages. Extensive use of computer graphics. Intended to prepare students to take an active role in the development of CAD software. Topics include computer graphics, data structures, 3-D modeling, role of new languages (LISP, PROLOG, etc.), and program development and debugging.]

590 Mechanical Engineering Design
Spring. 4 credits. Intended for students in M.Eng.(Mechanical) program.
Formal consideration of the complete design process (including creativity, planning, scheduling, cost analysis, management, and analytical methods) in the context of one or more specific projects carried out by the students. Projects may arise from department research interests or industrial collaboration.

610 Solid Modeling
Fall or spring. 4 credits. Prerequisites: graduate standing, at least two years of engineering mathematics, programming competence.
3 lecs. H. Voelcker.
Development of mathematical and computational methods of modeling one-, two-, and three-dimensional solids, using principles from geometry, topology, and computer science. M&AE 610 focuses on models and representations; a sequel, M&AE 611, focuses on algorithms, applications, and systems that use solid models. The pair provide foundations for CAD/CAM research and system development.

611 Applications of Solid Modeling
Spring. 2–4 credits to be arranged. Prerequisites: M&AE 610 or permission of instructor.
H. Voelcker.
Continuation of M&AE 610 with a focus on applications—specifically, a study of algorithms based mainly on set membership classification, together with their design and use in programs and systems for mechanical design and manufacturing (CAD/CAM).

612 Motional-Process Modeling: Manipulation and Machining
Spring, on demand. 4 credits. Prerequisites: M&AE 326, 478, and 610, or permission of instructor.
2 lecs, 1 lab by arrangement.
H. Voelcker.
Modeling of the spatial and dynamical behavior of machine tools and industrial robots, using principles from geometric modeling, classical dynamics, manufacturing-process dynamics, and control theory. Characterization of the performance of machine tools and robots in terms of physical architectures, control strategies, and software environments.

[665 Advanced Topics in Orthopaedic Biomechanics
Spring. 4 credits. Prerequisites: graduate standing, prior or concurrent registration in advanced courses in strength of materials or elasticity, and intermediate dynamics. Offered alternate years. Not offered 1990–91.
3 lecs. D. L. Bartel.
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.]

670 Mechanical and Aerospace Structures II: Finite-Element Method for Linear Mechanics
Spring. 4 credits. Prerequisite: M&AE 569 or permission of instructor. Fulfills computer applications requirement.
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 the numerical solution of boundary-value problems. Secondary consideration of inherent capabilities and limitations of large, general-purpose structural mechanics programs. Introduction to computational aspects through development of small, special-purpose program segments and the application of large, general-purpose programs. Term project.

678 Optimal Control and Estimation
Fall, on demand. 3 credits. Prerequisite: M&AE 478, EE 471, or permission of instructor; programming ability in FORTRAN, Pascal, or C. Corequisite: EE 521.
3 lecs. M. L. Psiaki.
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.

679 Modeling and Simulation of Dynamic Systems
On demand. 4 credits. Open to qualified undergraduates with permission of instructor.
J. F. Booker.
Modeling and representation of physical systems by systems of linear and nonlinear ordinary differential equations in state variable form. Selected applications from diverse fields. Simulation by numerical integration. Components and organization of general-purpose, digital-simulation languages (such as DSL and CSMP). Special techniques for large linear systems. Term project.

[682 Hydrodynamic Lubrication: Fluid-Film Bearings
Fall, on demand. 4 credits. Not offered 1990–91.
J. F. Booker.
Theory of hydrodynamic lubrication and its application to the analysis and design of fluid-film bearings and other devices. General topics include viscous flow in thin films, self-acting and externally pressurized bearings with liquid and gas lubricant films, bearing-system dynamics, and computational methods. Selected special topics such as elastohydrodynamic lubrication and artificial joints. Term project.]

[685 Optimum Design of Mechanical Systems
Fall. 4 credits. Prerequisite: graduate standing or permission of instructor. Offered alternate years. Not offered 1990–91.
D. L. Bartel.
The formulation of design problems frequently encountered in mechanical systems as optimization problems. Theory and application of methods of mathematical programming for the solution of optimum design problems.]

[715 Theory and Practice in Inelastic Deformation
Fall. 4 credits. Prerequisites: graduate standing and introductory finite-element course, or permission fo instructor. Offered alternate years. Not offered 1990–91.
G. G. Weber.
Topics in finite-deformation inelasticity in the framework of modern continuum mechanics. Material and geometric non-linear formulations on theoretical as well as practical grounds. Emphasis is on developing the underlying principles for proper formulation of engineering boundary-value problems with inelastic constitutive equations. Introductory small-scale simulations to illustrate the principles are also developed. Applications include inelastic design, metal forming, polymer processing, ice mechanics, and powder consolidation. Familiarity with compact tensor notation is recommended but not required.]

[716 Advanced Deformation Process Simulation
Spring. 4 credits. Prerequisites: graduate standing and M&AE 715, or permission of instructor. Offered alternate years. Not offered 1990–91.
P. R. Dawson.
Application of advanced mechanics theories to the simulation of the deformations of solids, with special attention toward materials processing and other severe-loading environments. The selection of model equations based on dominant features of the material behavior and kinematics of a particular application is stressed. The use of state-variable constitutive models are discussed, including micromechanical models such as those of polycrystal plasticity. Assignments consist of simulation projects that assume a working knowledge of the finite-element method.]

Energy, Fluids, and Aerospace Engineering

405 Introduction to Aeronautics
Fall. 3 credits. Limited to upperclass engineers; others with permission of instructor.
Introduction to atmospheric-flight vehicles. Principles of incompressible and compressible aerodynamics, boundary layers, and wing theory. Propulsion system characteristics. Static aircraft performance; range and endurance. Elements of stability and control.

[439 Acoustics and Noise
Spring. 3 credits. Prerequisite: some knowledge of fluid mechanics or permission of instructor. Not offered 1990–91.
Sound propagation, transmission, and absorption. Sound radiation by surfaces and flow. Loudspeakers. Room acoustics and noise-control techniques. Hearing, music, noise, and noise-control criteria.]

[441 Advanced Thermodynamics with Energy Applications
Spring. 3 credits. Prerequisites: M&AE 221 and 323, or permission of instructor.
3 lecs. Not offered 1990–91.
Brief review of classical thermodynamics. Applications to power cycles and refrigeration cycles of particular interest to energy systems. Other topics include the thermodynamic properties of pure systems, phase and chemical equilibria. Brief introduction to statistical thermodynamics.]

449 Combustion Engines
Spring. 3 credits. Prerequisites: Engr 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.

[506 Aerospace Propulsion Systems
Spring. 3 credits. Prerequisite: M&AE 323 or permission of instructor. Offered alternate years. Not offered 1990–91.
3 lecs.
Application of thermodynamic and fluid-mechanic principles to the design and performance of aerospace systems. Jet propulsion principles, including rockets. Pollution characteristics. Future possibilities for improved performance.]

507 Dynamics of Flight Vehicles
Spring. 3 credits. Prerequisites: M&AE 405 and Engr 203, or permission of instructor. Offered alternate years.
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 and transient control response. At the level of *Dynamics of Flight: Stability and Control*, by Etkin.

530 Fluid Dynamics
Fall. 3 credits. Prerequisites: M&AE 323 and senior or graduate standing, or permission of instructor.
Inviscid fluid dynamics and aerodynamics, including imcompressible and supersonic flows, flow over bodies, lift, and drag. Shock waves. Courses 530 and 531 are of interest primarily to seniors and M.Eng. students; however, incoming M.S. or Ph.D. students who will not major in fluid mechanics but need competence in problem solving and basic problem formulation should be interested also. The courses may be taken independently or as a sequence.

531 Boundary Layers
Spring. 3 credits. Prerequisites: M&AE 323 and senior or graduate standing, or permission of instructor. Recommended: M&AE 530 or equivalent.
Review of the Navier-Stokes equation, simple exact solutions, concept of scaling. Classical laminar boundary layer theory. Physical mechanisms of boundary layer formation; flat plate boundary layer. Method of matched asymptotic expansions for singular perturbation problems of boundary layer type. Similarity solutions. Blasius series for boundary layer flow past an arbitrary two-dimensional body. Behavior of boundary layer flows near a separation point. Interactive boundary layer theory. Concepts of stability and transition to turbulence. Deterministic chaos. Some results of stability theory for boundary layers. Fully developed turbulence, turbulent wall layer structure, turbulent boundary layers.

536 Turbomachinery and Applications
Spring. 3 credits. Prerequisite: M&AE 323 or equivalent.
3 lecs. F. K. Moore.
Aerothermodynamic design of turbomachines in general, energy transfer between fluid and rotor in specific types, axial and radial devices, compressible flow. Three-dimensional effects, surging.

543 Combustion Processes
Spring. 3 credits. Prerequisites: M&AE 323 and 324.
3 lecs. F. C. Gouldin.
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, combustion of solids.

554 Solar Engineering Design
Spring. 3 credits. Prerequisites: M&AE 428 and senior standing in M&AE. Fulfills field design requirement. Enrollment limited to 30.
A broad coverage of solar-energy utilization by humankind. Fundamentals of solar radiation. Direct radiation as a source of heat and work. Indirect radiation utilization or natural collection; water power, windpower, and biomass. The production of liquid and gaseous fuels. Solar architecture and environmental control by both active and passive means. Each student will execute a design project in solar engineering. Course grade will be based on the design project; presentation of a design proposal, an oral presentation on progress of project, and submission of a final design report.

556 Power Systems
Fall. 3 credits. Corequisites: M&AE 428 and senior standing. Fulfills field design requirement.
P. L. Auer.
A broad survey of methods of large-scale power generation, emphasizing energy sources, thermodynamic cycle considerations, and component description. Power-industry, economic, and environmental factors, trends, and projections.

559 Introduction to Controlled Fusion: Principles and Technology (also EE 484 and NS&E 484)
Spring. 3 credits. Prerequisites: Physics 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics with permission of instructor. Intended for seniors and graduate students.
3 lecs.
This course is intended to give engineering and physical science students an introduction to the physical basis and technological requirements for generating useful power by nuclear fusion. For complete description see NS&E 484.

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.

602 Incompressible Aerodynamics
Fall or spring. 4 credits. Prerequisite: M&AE 601 or equivalent. Open to qualified undergraduates with permission of instructor.
Basic equations for inviscid fluid motion. Vorticity dynamics. General results for irrotational flows. Integral representations via Green's theorem. Solution methods based on singularities. Complex variable technique for two-dimensional flows. Airfoil, wing, and slender-body theories. Unsteady phenomena. Three-dimensional boundary layers and separation.

603 Compressible Aerodynamics
Fall. 4 credits. Prerequisite: M&AE 601 or equivalent, or permission of instructor.
Basic conservation laws and fundamental theorems of compressible fluid flow. The accoustic approximation. One-dimensional unsteady flows. Characteristics and shock waves. Exact solutions of steady flows. General methods for two-dimensional and axisymmetric steady flows and Bateman principles. Hodograph method. Characteristics method for steady supersonic flows. Approximate methods, series expansion, and perturbation theories; transonic and hypersonic flows.

608 Physics of Fluids
Fall. 4 credits. Prerequisite: graduate standing or permission of instructor.
F. C. Gouldin.
Kinetic theory of gases: collisions; transport properties; derivation of the macroscopic equations of mass, momentum, and energy. Statistical mechanics of gases: microcanonical ensemble; partition functions; calculation of thermodynamic properties. Introduction to wave mechanics: harmonic oscillator, rigid rotator, one-electron atom. Atomic and molecular structure: building-up principle, Born-Oppenheimer approximation.

630 Atmospheric Turbulence and Micrometeorology
Spring, on demand. 4 credits. Open to qualified undergraduates with permission of instructor.
Z. Warhaft.
Basic problems associated with our understanding of the structure of the velocity field and the transport of scalars such as temperature and moisture in the lower atmosphere from both theoretical and experimental viewpoints. Topics include the second-order turbulence equations and their closure; Monin-Obukhov theory; diffusion of scalars; spectral characteristics of atmospheric variables; experimental techniques, including remote sensing; and the analysis of random-time series.

639 Aerodynamic Noise Theory
Fall. 4 credits. Prerequisites: Graduate standing and knowledge of fluid mechanics, or permission of instructor.
3 lecs. A. R. George.
Topics in acoustics relevant to transportation noise sources and control. Lighthill and Ffowcs Williams formulations for sound generation. Deterministic and broadband sources. Propagation, nonlinear effects, absorption, diffraction, and transmission. Applications to aircraft, automobiles, propellers, fans, etc.

651 Advanced Heat Transfer
Spring. 4 credits. Prerequisite: graduate standing or permission of instructor.
M. Y. Louge.
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.

652 Thermodynamics and Phase-Change Heat Transfer (also Chem E 721)
Spring, on demand. 4 credits. Prerequisite: graduate standing or permission of instructor.
C. T. Avedisian.
Thermodynamics of phase change. Superheated liquids and supersaturated vapors. Thermodynamic stability criteria for metastable liquids and homogeneous nucleation theory. Dynamics of bubble growth and collapse. Pool boiling and the critical heat flux. Hydrodynamics of one-dimensional two-phase flows.

653 Experimental Methods in Fluid Mechanics, Heat Transfer, and Combustion
Spring. 4 credits.
2 lecs, 1 lab. Z. Warhaft.
Study of experimental techniques for measuring pressure, temperature, velocity, and composition of gases, with emphasis on experimental capabilities and physical principles. Topics include laser velocimetry, hot-wire anemometry, spectroscopy, and laser scattering.

[704 Viscous Flows
Fall or spring. 4 credits. Prerequisites: M&AE 601 or T & AM 610, or permission of instructor. Offered alternate years. Not offered 1990–91.
S. F. Shen.
A systematic study of laminar-flow phenomena (including compressibility and heat transfer) and methods of analysis. Exact solutions of the Navier-Stokes equations. Linearized problems; flow at small Reynolds numbers, laminar instability. The boundary-layer approximation; general properties. Transformations for compressibility and axisymmetric effects. Approximate methods of calculation. Separation and unsteady problems. Stability of laminar flows.]

[732 Analysis of Turbulent Flows
Spring. 4 credits. Prerequisite: M&AE 601 or permission of instructor. Offered alternate years. Not offered 1990–91.
S. B. Pope.
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.]

733 Stability of Fluid Flow
Fall. 4 credits. S-U grades only. Prerequisite: graduate standing or permission of instructor. Offered alternate years. May be offered 1990–91.
S. Leibovich.
Introduction to stability and bifurcation of fluid flow. Energy stability theory. Convective instability, the Benard problem. Taylor instability of rotating couette flow. Stability of parallel flows. Critical-layer singularities and methods of resolution. Boundary layers, slight departures from parallel flow. Stratified flows and the Taylor-Goldstein equation; swirling flows. Destabilization by "stabilizing" body forces. Nonlinear effects: amplitude equations of the Stuart-Watson type. Modulated nonlinear effects and amplitude equations of the Newell-Whitehead type. Nonlinear critical-layer dynamics.

734 Turbulence and Turbulent Flow
Fall. 4 credits. Prerequisite: M&AE 601 or permission of instructor.
J. L. Lumley.
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.

736 Computational Aerodynamics
Spring. 4 credits. Prerequisites: graduate standing, an advanced course in continuum mechanics or fluid mechanics, and some FORTRAN programming experience.
3 lecs. D. A. Caughey.
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 digital computer.

737 Computational Fluid Mechanics and Heat Transfer
Fall. 4 credits. Prerequisites: graduate standing; an advanced course in continuum mechanics, heat transfer, or fluid mechanics; and some FORTRAN programming experience.
K. E. Torrance.
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 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 and at CADIF.

Special Offerings

001 Introduction to Mechanical Technology
Fall, spring. 1 credit. Enrollment limited. S-U grades only. Does not meet any graduation requirements. May be offered 1990–91.
1 sec.
Offered to students lacking a background in basic understanding of mechanical devices and technology. Hands-on experience with various typical devices such as engines, refrigeration units, heat pumps, etc.

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.

491 Design Projects in Mechanical and Aerospace Engineering
Fall, spring. 3–6 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.

520 Mechanical Tolerancing and Dimensional Metrology
Spring. 2 credits. Prerequisites: Math 294 and Engr 102; M & AE 312 is helpful. Seven-week course. May be offered 1990–91.
2 lecs. H. B. Voelcker.
Current industrial practices in mechanical tolerancing and dimensional metrology, based on the national tolerancing standard ANSI Y14.5. Discussion of weaknesses in current methods, and emerging formal theories. Lab experience with manual instruments, functional gauges, coordinate-measuring and surface-measuring machines.

592 Seminar and Design Project in Aerospace Engineering
Fall, spring. 2 credits each term. 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.

594 Manufacturing Seminar (also OR&IE 894)
Fall, spring. 1 credit. S-U grades optional.
1 sec.
A weekly, practice-oriented seminar with external speakers for Master of Engineering students in several disciplines who are interested in manufacturing. Conducted in cooperation with the School of Operations Research and Industrial Engineering, the Cornell Manufacturing Engineering and Productivity Program (COMEPP), and the Cornell Society of Engineers.

690 Special Investigations in Mechanical and Aerospace Engineering
Fall, spring. Credit to be arranged. Limited to graduate students.

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. Two offerings are projected. 1) Seminar in Robotics, by J. C. Koechling (fall or spring); an overview of the design, control, and use of manipulators, from their early development to the present, through the reading and discussion of papers. 2) Chaotic Vibrations, by F. C. Moon (spring); review of classical nonlinear vibration theory, maps and flows, routes to chaos, mathematical models of chaotic physical systems, experimental Poincaré maps, theoretical predictive phenomena, Lyapunov exponents, measures of fractal dimensions, and fractal basin boundaries.

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.

794 Graduate Seminar in Manufacturing Processes
Fall, spring. 1 credit. S-U only. Prerequisites: Graduate standing and permission of instructor.
1 sec. K. K. Wang.
A weekly seminar giving graduate students who are working on manufacturing research topics an opportunity to present their work and discuss it with other students and staff. Participation of full-time research associates is also anticipated.

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.

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.

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 the 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, 634, 636, 638, and 651).

121 Fission, Fusion, and Radiation (also Engr 121)
Spring. 3 credits.
2 lecs, 1 lab demonstration.
This is a course in the Introduction to Engineering series. For description see Engineering Common Courses.

303 Introduction to Nuclear Science and Engineering I (also A&EP 303)
Fall. 3 credits. Prerequisite: Physics 214 or 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.
3 lecs. V. O. Kostroun.
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.

484 Introduction to Controlled Fusion: Principles and Technology (also EE 484 and M&AE 559)
Spring. 3 credits. Prerequisites: Physics 112, 213, and 214, or equivalent background in electricity and magnetism and mechanics, and permission of instructor. Intended for seniors and graduate students.
3 lecs. D. A. Hammer.
Introduction to the physical principles and technology underlying controlled-fusion power. Topics include fundamental aspects of the physics of ionized gases at high temperature (thermonuclear plasmas), requirements (in principle) for achievement of net power from fusion, technological problems of an actual fusion reactor, and progress of the fusion program toward overcoming these problems. Both magnetic and inertial confinement fusion are discussed, and comparisons are made between fusion and fission.

551 Nuclear Methods in Non-Nuclear Research Fields
Spring. 3 credits. Prerequisite: Physics 214 or 218, or permission of instructor; some upper-division physics desirable. Primarily for graduate students in 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, which has the same lecture but has an additional lab period, is intended for nuclear specialists.
One 2-hour lecture and one 2-1/2-hour lab. D. D. Clark.
Lectures on interaction of radiation with matter, radiation protection, and nuclear instruments and methods including data reduction. About ten experiments are available on radiation detection, attenuation, 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 those nuclear methods, particularly instrumental ones using neutrons, that are used in, or are being adapted for, non-nuclear fields, but tracer and other chemical techniques are not included. Students each select seven or eight experiments to meet their interests and needs. At the level of *Nuclear Analytical Chemistry*, by Brune, Forkman, and Persson.

621 Radiation Effects in Microelectronics
Fall. 3 credits. Prerequisite: Permission of instructor. A seminar intended for seniors and graduate students in engineering or applied physics.
T Th 9:00–10:00, two 1-1/2 hour lectures. S. C. McGuire.
An introduction to the physical processes that underlie the malfunction of microelectronic circuitry resulting from exposure to ionizing radiation. Basic device-failure mechanisms, including total-dose effects, single-event upsets, and latchup, as well as the roles that circuit testing and modeling methods play in improving circuit design. Impact of surface radiation typical of low-energy electron and photon sources on device fabrication. Reference materials from the current literature.

OPERATIONS RESEARCH AND INDUSTRIAL ENGINEERING

115 Engineering Application of Operations Research (also Engr 115)
Fall, spring. 3 credits. Enrollment not open to OR&IE upperclass majors.
2 lecs, 1 lab.
For description see Engineering Common Courses.

119 Introduction to Manufacturing (also Engr 119 and M & AE 119)
Spring. 3 credits. Enrollment not open to OR&IE upperclass majors.
2 lecs, 1 lab.
For description see Engineering Common Courses.

230 Discrete Mathematics
Spring. 3 credits. Prerequisite: one year of calculus or permission of instructor.
3 lecs.
A broad but thorough introduction to topics of discrete mathematics of use in a variety of fields of science and engineering. Topics include basic combinatorics and counting techniques, recurrence relations and generating functions, introduction to modular arithmetic with application to coding theory and experimental designs, and basic notions of graph theory with applications in optimization such as maximum flow in a network and project planning.

260 Introductory Engineering Probability (also Engr 260)
Fall, spring, summer. 3 credits. Prerequisite: first-year calculus. Corequisite: Math 293.
3 lecs.
For description see Engineering Common Courses.

270 Basic Engineering Probability and Statistics
Fall; also spring, summer if staffing permits. 3 credits. Prerequisite: first-year calculus. Enrollment not open to OR&IE upperclass majors.
3 lecs. Evening prelims.
For description see Engineering Common Courses.

320 Optimization I
Fall. 4 credits. Prerequisite: Mathematics 221 or 294.
3 lecs, 1 rec.
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.

321 Optimization II
Spring. 4 credits. Prerequisite: OR&IE 320 or equivalent.
3 lecs, 1 rec.
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.

350 Cost Accounting, Analysis, and Control
Fall; also spring if staffing permits. Upper-class standing only; enrollment limited. 4 credits.
3 lecs, 1 computing-disc.
Principles of accounting, financial reports; job-order and process cost systems—historical and standard costs; cost characteristics and concepts for control, analysis, and decision making.

361 Introductory Engineering Stochastic Processes I
Spring. 4 credits. Prerequisite: OR&IE 260 or equivalent.
3 lecs, 1 rec.
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 queueing and reliability.

370 Introduction to Statistical Theory with Engineering Applications
Fall. 4 credits. Prerequisite: OR&IE 260 or equivalent.
3 lecs, 1 rec.
Provides a working knowledge of basic statistics as it is most often applied in engineering and a basis in statistical theory for continued study. Topics include a review of distributions of special interest in statistics; testing simple and composite hypotheses; point and interval estimation; correlation; linear regression.

410 Industrial Systems Analysis
Spring. 4 credits. Corequisite: OR&IE 270 or 370.
3 lecs, 1 computing session.
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.

416 Design of Manufacturing Systems
Spring (last 4 weeks). 3 credits. Seniors and graduate students only. Corequisites: at least one of the following courses: OR&IE 417, 451, 525, and 562.
2 lecs.
Project course in which students, working in teams, design a manufacturing and/or logistics system and conduct capacity, material flow, and cost analysis of their design. Meetings between project teams and faculty advisers are substituted for most lectures.

417 Layout and Material Handling Systems
Spring. 3 credits. Prerequisite: OR&IE 361.
2 lecs, 1 rec.
Design of the layout of processes and storage areas and the material- handling system for movement of items. Typical equipment used. The functions of identification control, storage, movement, batching, merging, and dispersion. Introduction to new technologies.

421 Production Planning and Control
Fall. 4 credits. Prerequisites: OR&IE 320 and 361, or permission of instructor.
3 lecs, 1 rec.
Introduction to the design, planning, and control of production and distribution systems. Decision making in manufacturing systems is stressed. Topics include inventory planning, work-cell design, work-load smoothing, production planning, and scheduling.

431 Discrete Models
Spring. 4 credits. Prerequisites: OR&IE 320 and CS 211, or permission of instructor.
3 lecs, 1 rec.
Basic concepts of graphs, networks, and discrete optimization. Fundamental models and applications, and algorithmic techniques for their analysis. Specific models studied include flows in networks, network synthesis, sequencing, partitioning, and fair allocation.

[432 Applied Linear Algebra and Introductory Nonlinear Programming
Fall. 3 credits. Prerequisite: Math 294 or 221. Not offered 1990–91.
Emphasis is on the ideas and theory of linear algebra that are especially important in optimization applications. Linear techniques are developed in the context of basic nonlinear programming to illustrate how linear algebra is used to study nonlinear systems. Some assignments provide exposure to existing software; other assignments require careful mathematical thought and exposition.]

435 Introduction to Game Theory
Fall. 3 credits.
3 lecs.
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.

451 Economic Analysis of Engineering Systems
Spring. 3 credits. Prerequisites: OR&IE 320 and OR&IE 350.
2 lecs, 1 computing session.
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.

462 Introductory Engineering Stochastic Processes II
Spring. 4 credits. Prerequisite: OR&IE 361 or equivalent.
3 lecs, 1 rec.
A selection of topics from the following: martingales, Markov and semi-Markov processes, optimal stopping. Examples and applications are drawn from several areas.

472 Statistical Decision Theory
Fall. 3 credits. Prerequisite: OR&IE 370 or equivalent.
3 lecs.
Decision rules, admissible decision rules, Bayes decision rules, minimax decision rules. Using regret instead of loss. Criteria for choosing a decision rule and relation to theory of games. Use of linear programming to construct minimax decision rules. Building cost of collecting information into the loss function. Decision problems requiring a sequence of decisions over time and relation to dynamic programming. Use of the empirical cumulative distribution function and applications to inventory problems. Classical statistical theory as special cases of statistical decision theory.

475 Regression
Fall. Second half of term. 2 credits. Prerequisite: OR&IE 370.
3 lecs, 1 rec.
Linear models; estimation and testing; confidence sets; diagnostics and residual analysis; variable selection and modeling.

476 Experimental Design I
Fall. First half of term. 2 credits. Prerequisite: OR&IE 370.
3 lecs, 1 rec.
One- and two-way ANOVA; blocking with one or two factors; replication and sample-size determination; multiple comparison; selection of best population(s).

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.

516 Case Studies
Fall. 4 credits. Only for M.Eng. students in OR&IE.
3 rec-labs.
Students are presented with unstructured problems that resemble real-world situations. Students work in project groups on the formulation of mathematical models, computer analysis of the data and models, and presentation of oral and written reports.

520 Operations Research I: Optimization I
Fall. 4 credits. Prerequisite: Mathematics 221 or 294. Intended for graduate students minoring in operations research. The same course as OR&IE 320, but on the graduate level.
3 lecs, 1 rec.
For description see OR&IE 320.

521 Optimization II
Spring. 4 credits. Prerequisite: OR&IE 320 or 520 or equivalent. Intended for graduate students in other fields. Lectures concurrent with OR&IE 321.
3 lecs, 1 rec.
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.

523 Operations Research II: Introduction to Stochastic Modeling
Spring. 4 credits. Prerequisite: OR&IE 260 or equivalent. Intended for graduate students in other fields. Lectures concurrent with OR&IE 361.
3 lecs, 1 rec.
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.

[525 Scheduling Theory
Spring. 3 credits. Prerequisite: OR&IE 320. Not offered 1990–91.
3 lecs.
Scheduling and sequencing problems. Single-resource scheduling, parallel processing, flow-shop scheduling. Methodology is drawn from dynamic and integer programming, simulation techniques, and heuristic methods.]

561 Queuing Theory and Its Applications
Fall. 3 credits. Prerequisite: OR&IE 361 or permission of instructor.
3 lecs.
Basic queuing models. Delay and loss systems. Finite source, finite capacity, balking, reneging. Systems in series and in parallel. Various queue disciplines. Busy-period problems. Design and control problems. Statistical inference from queuing processes. Priority systems. Queuing networks. Applications to equipment maintenance, telephone traffic, and computer operations.

562 Inventory Theory
Spring. 3 credits. Prerequisite: OR&IE 421 or permission of instructor.
3 lecs, 1 rec.
Discussion of the nature of inventory systems and their design and control. Periodic and continuous review policies for single-item and single-location problems. Multi-item and multi-echelon extensions. Dynamic and static models are discussed. Distribution problems are analyzed. Applications are stressed.

[563 Applied Time-Series Analysis
Fall. 3 credits. Prerequisites: OR&IE 361 and 370 and CS 211, or permission of instructor. Not offered 1990–91.
3 lecs.
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. As time permits other topics, such as spectral analysis, filtering and long-range dependence are discussed. Analysis of real data is carried out. Assignments require computer work.]

564 Introductory Engineering Stochastic Processes II
Spring. 4 credits. Prerequisite: OR&IE 361 or equivalent. Lectures concurrent with OR&IE 462.
3 lecs, 1 rec.
For description see OR&IE 462.

570 Introduction to Statistical Theory with Engineering Applications
Fall. 4 credits. Prerequisite: OR&IE 260 or equivalent. Lectures concurrent with OR&IE 370.
3 lecs, 1 rec.
For description see OR&IE 370.

[575 Experimental Design II
Spring. Half of term. 2 credits. Prerequisite: OR&IE 475. Not offered 1990–91.
3 lecs, 1 rec.
2^N factorials; confounding; 2^{N-P} and 3^{N-P} fractional factorials.]

[577 Quality Control
Spring, if staffing permits. 3 credits. Prerequisites: OR&IE 270 or 370. Not offered 1990–91.
3 lecs, 1 rec.
Control concepts and methods for attributes and variables; process capability analysis; acceptance sampling plans; elementary procedures for variables; acceptance-rectification procedures.]

580 Design and Analysis of Simulated Systems
Fall. 4 credits. Prerequisites: CS 211 and OR&IE 370, or permission of instructor.
3 lecs, 1 rec.
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.

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.

626 Advanced Production and Inventory Planning
Fall. 3 credits.
3 lecs.
Introduction to a variety of production and distribution planning problems; the development of mathematical models corresponding to these problems; a study of approaches for finding solutions.

[627 Dynamic Programming
Fall. 3 credits. Prerequisite: permission of instructor. Not offered 1990–91.
3 lecs.
Optimization of sequential decision processes. Deterministic and stochastic models, infinite-horizon Markov decision models, policy iterations. Contraction mapping methods. Applications drawn from inventory theory, production control.]

630–631 Mathematical Programming I and II
630, fall; 631, spring. 3 credits each term. Prerequisites: advanced calculus and elementary linear algebra.
3 lecs.
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. Introduction to new algorithms (ellipsoid, Karmarkar). Exploiting special structure in the simplex method, computational implementation. Decomposition Principle. Introduction to integer and nonlinear programming and game theory.

[632 Nonlinear Programming
Fall. 3 credits. Prerequisite: OR&IE 630. Not offered 1990–91.
3 lecs.
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.]

633 Graph Theory and Network Flows
Fall. 3 credits. Prerequisite: permission of instructor.
3 lecs.
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.

[634 Combinatorial Optimization
Spring. 3 credits. Prerequisite: permission of instructor. Not offered 1990–91.
3 lecs.
Topics in combinatorics, graphs, and networks, including matching, matroids, polyhedral combinatorics, and optimization algorithms.]

635 Interior-Point Methods for Mathematical Programming
Spring. 3 credits. Prerequisites: Math 411 and OR&IE 630, or permission of instructor.
3 lecs.
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.

636 Integer Programming
Fall. 3 credits. Prerequisite: OR&IE 630.
3 lecs.
Discrete optimization. Linear programming in which the values are restricted to integers. Theory, algorithms, and applications. Cutting-plane methods, enumerative methods, and group-theoretic methods; additional topics are drawn from recent research in this area.

[639 Convex Analysis
Spring. 3 credits. Prerequisite: Mathematics 411 and 431, or permission of instructor. Not offered 1990–91.
3 lecs.
The theory of finite dimensional convex sets is developed through the study of real-valued convex functions and Fenchel duality. Separation of convex sets, polarity correspondences, recession cones, theorems of Helly and Caratheodory.]

660 Applied Probability
Fall. 4 credits. Prerequisite: advanced calculus.
3 lecs, 1 rec.
Introduction to basic probability. The sample space; events; probability. Conditional probability. Independence. Product spaces. Random variables. Expectation. Important distributions. Characteristic functions. Convergence concepts. Limit theorems.

661 Applied Stochastic Processes
Spring. 4 credits. Prerequisite: OR&IE 660 or equivalent.
3 lecs, 1 rec.
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, point processes.

662 Advanced Stochastic Processes
Spring. 3 credits. Prerequisite: OR&IE 661 or equivalent.
3 lecs.
A selection of topics from the following: stationary processes, Levy processes, diffusion processes, point processes, martingales, regenerative phenomena, random walks, stochastic calculus, weak convergence.

663 Time-Series Analysis
Spring. 3 credits. Prerequisite: OR&IE 660 or equivalent.
3 lecs.
Representations of stationary time series. The ARIMA models. Spectral analysis. Long-range dependence. Problems of estimation. Multivariate time series.

[665 Advanced Queuing Theory
Fall. 3 credits. Prerequisite: OR&IE 660 or equivalent. Not offered 1990–91.
3 lecs.
A study of stochastic processes arising in a class of problems including congestion, storage, dams, and insurance. The treatment is self-contained. Transient behavior of the processes is emphasized. Heavy-traffic situations are investigated.]

670 Statistical Principles
Spring. 4 credits. Prerequisite: OR&IE 660 or equivalent.
3 lecs, 1 rec.
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.

671 Intermediate Applied Statistics
Fall. 3 credits. Prerequisite: OR&IE 670 or equivalent.
3 lecs.
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.

[674 Design of Experiments
Spring. 3 credits. Prerequisite: OR&IE 671 or permission of instructor. Not offered 1990–91.
3 lecs.
Use and analysis of experimental designs such as randomized blocks, balanced incomplete blocks, and Latin squares; analysis of variance and covariance, factorial experiments; statistical problems associated with finding best operating conditions; response-surface analysis.]

676 Statistical Analysis of Life Data
Spring. 3 credits. Prerequisite: OR&IE 671 or equivalent.
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.

[678 Asymptotic Methods in Statistics
Spring. 3 credits. Prerequisite: OR&IE 670 or Mathematics 574. Not offered 1990–91.
Large-sample behavior of MLEs and other estimates; chi-square, likelihood ratio, and related tests; Pitman and Bahadur efficiency; LAN families and LAM estimates; statistical applications of Edgeworth expansions; adaptive estimation and semiparametric inference.]

[680 Simulation
Spring. 3 credits. Prerequisite: permission of instructor. Not offered 1990–91.
3 lecs.
An advanced version of OR&IE 580, intended for Ph.D.-level students.]

728–729 Selected Topics in Applied Operations Research
Fall, spring. Credit to be arranged.
Current research topics dealing with applications of operations research.

738–739 Selected Topics in Mathematical Programming
Fall, spring. Credit to be arranged.
Current research topics in mathematical programming.

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.

778–779 Selected Topics in Applied Statistics
Fall, spring. Credit to be arranged.
Topics chosen from current literature and research of the staff.

790 Special Investigations
Fall, spring. Credit to be arranged.
For individuals or small groups. Study of special topics or problems.

799 Thesis Research
Fall, spring. Credit to be arranged.
For individuals doing thesis research for master's or doctoral degrees.

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.

893–894 Applied OR&IE Colloquium (894 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

123 Sensors and Actuators (also Engr 123)
Fall. 3 credits.
2 lecs, 1 lab.
For description see Engineering Common Courses.

202 Mechanics of Solids (also Engr 202)
Fall, spring. 3 credits. Prerequisite: coregistration in Mathematics 293.
2 lecs, 1 rec, 4 labs each semester, evening exams.
For description see Engineering Common Courses.

203 Dynamics (also Engr 203)
Fall, spring. 3 credits. Prerequisite: coregistration in Mathematics 294.
2 lecs, 1 rec, 4 labs each semester, evening exams.
For description see Engineering Common Courses.

281 Structures and Machines in Urban Society (also Engr 281)
Fall. 3 credits.
R. Lance.
For description see Engineering Common Courses.

293 Engineering Mathematics
Fall, spring. 4 credits. Prerequisite: Mathematics 192 or 194.
2 lecs, 1 rec, 4 labs during semester, evening exams.
Partial derivatives and multiple integrals; first- and second-order ordinary differential equations with applications in the physical and engineering sciences. Includes microcomputer experiments using computer algebra to solve problems.

294 Engineering Mathematics
Fall, spring. 4 credits. Prerequisite: Mathematics 293.
2 lecs, 1 rec, 4 labs during semester, evening exams.
Vector spaces and linear algebra, matrices, eigenvalue problems, and applications to systems of linear differential equations. Vector calculus. Boundary-value problems and introduction to Fourier series. Includes microcomputer experiments using computer algebra to solve problems.

Engineering Mathematics

310 Advanced Engineering Analysis I
Fall, spring. 3 credits. Prerequisite: Mathematics 294 or equivalent.
2 lecs, 1 rec.
Ordinary differential equations as applied in engineering context. Analytical and numerical methods. Special functions, initial value, boundary value, and eigenvalue problems in linear partial differential equations; introduction to nonlinear ordinary differential equations. Use of computer algebra and MACSYMA to solve problems.

311 Advanced Engineering Analysis II
Spring. 3 credits. Prerequisite: T&AM 310 or equivalent.
Functions of several variables, introduction to complex variables, analytic functions, conformal mapping, method of residues. Application to the solution of Laplace's equation, and transform inversion techniques. Examples drawn from fluid mechanics, heat transfer, electromagnetics, and elasticity.

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.
3 lecs.
Emphasis is on applications. Linear algebra, calculus of several variables, vector analysis, series, ordinary differential equations, complex variables.

611 Methods of Applied Mathematics II
Spring. 3 credits. Prerequisite: T&AM 610 or equivalent.
3 lecs.
Emphasis on applications. Partial differential equations, transform techniques, tensor analysis, calculus of variations.

612 Methods of Applied Mathematics III
Fall. 3 credits. Prerequisite: T&AM 610 or 611 or equivalent. First of a 6-credit sequence (T&AM 612 and 613) that develops advanced mathematical techniques for engineers and applied physicists.
Review of complex variable theory, conformal mapping, special functions, integral transform, Wiener-Hopf technique, and singular integral equations. Problems drawn from electromagnetics, elasticity, fluid mechanics, heat transfer, and acoustics.

613 Methods of Applied Mathematics IV
Spring. 3 credits. Prerequisite: T&AM 612 or equivalent.
Topics include asymptotic behavior of solutions of linear and nonlinear ODE (e.g., the WKB 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 algebra (MACSYMA) exercises at the option of the instructor.

Continuum Mechanics

501 Topics in Composites I
Fall. 1 to 3 credits (1 credit each topical minicourse)
Analysis of Composite Structures (T. J. Healey)

Consideration of the simplest problems, seen in terms of classical linear theories of structural mechanics, with an emphasis on anisotropic material properties appropriate to composite structures. Small-deflection bending of thin, elastic beams; analysis of composite beams; small-deflection theory of thin, elastic plates; membrane theory of thin shells; analysis of composite plates and shells.

Biological Composites (J. T. Jenkins)

Overview of the microstructural features and origin of the mechanical properties of bone and soft tissues such as tendon, ligament, muscle, and skin; their use as structural components. Design principles for composite materials mimicking those found in biological systems.

Design Principles for Composite Structures (R. H. Lance)

Review of thermomechanical behavior of anisotropic, orthotropic, and transversely isotropic materials. Development of pertinent equations for laminated materials and sandwich structures. Application to design and analysis of rods, beams, tubes, and plates. Examples drawn from space structures.

Mechanical Testing of Composite Constituents (Staff)

Theoretical and experimental characterization of strength and life of advanced composite constituents and materials; review of test methods, specimen preparation, testing, data reduction, and analysis; conduct of laboratory experiments for short-term strength distribution of fiber material, interface-strength evaluation, and life strength.

Reliability Models for Composites (S. L. Phoenix)

Models for fiber strength and fatigue lifetime including flaw statistics, diameter and length effects, and the special role of the Weibull distribution; models for the failure of fiber bundles including the role of load sharing and fiber-breakdown laws; models for the strength and stress-rupture of unidirectional composites including the effects of fiber strength distributions and the micromechanics of fiber/matrix stress transfer including matrix creep.

Fracture Testing for Composites (A. Zehnder)

Fracture-mechanics models for fiber-reinforced composites and their ability to predict the fracture resistance of these materials; performance of simple fracture tests using standardized test methods as well as advanced experimental-mechanics techniques.

502 Topics in Composites II
Fall. 1 to 3 credits (1 credit each topical minicourse)
Interface Failure and Fracture Processes in Composites (H. Hui)

Fundamentals of elastic fracture mechanics, interface models for a number of composite systems, stiffness reduction, interface crack growth, and fracture toughness of simple composite structures.

Boundary-Element Methods for Composites (S. Mukherjee)

Boundary-element methods for potential and elasticity problems; modeling of anisotropic elasticity with applications to composites.

Software for Composite Design (Staff)

Introduction to software for the design of composite structures. Included are MATLAB, for matrix computations of orthotropic materials; GENLAM and LAMRANK, for the analysis and design of laminates; C-FRANC (interactive computer graphics), for simulating the fracture of unidirectional, fiber-reinforced composites; and SLAD, for probabilistic analysis of strength and life of fiber bundles and composites. Emphasis is on practical applications in the design of tubes, pressure vessels, beams, and plates.

Effective Properties of Composites (P. Rosakis)

Review of material anisotropy, field equations, and interface conditions for composite bodies, solutions of fundamental composite problems, Eshelby's inhomogeneity problem, self-consistent methods for computing effective moduli, layered media, periodic arrays of particles, introduction to basic concepts of homogenization theory.

Novel Composite Structures (A. Ruina)

The design of sports equipment, human-powered vehicles, and other high-performance structures fabricated from composite materials.

Nondestructive Testing of Composites (W. Sachse)

Issues of process control in composite fabrication, problems related to the inspection of composite components, integrity monitoring and damage assessment, survey of conventional and advanced nondestructive evaluation (NDE) methods for composites, sensors for composite NDE, directions in current NDE research applicable to composites.

555 Introduction to Composite Materials
Fall. 3 credits.
2 lecs, 6 labs per semester. R. H. Lance and staff.
Introduction to composite materials: varieties of reinforcements, matrix materials and their properties. Mechanics and failure analysis of lamina, laminates, and wound structures; introduction to micromechanics theories of composites, manufacturing methods, fabrication and assembly techniques, composite applications, environmental effects.

[569 Sensors
Fall. 3 credits. Not offered 1989–90.
3 lecs a week, 4 labs a semester.
This course deals with the general properties of sensors and actuators used in measurement and process-control applications involving thermal and mechanical quantities. Considered are sensors and actuators based on a broad range of physical transduction phenomena. Attention is given to the development of sensor models and criteria for evaluating the general performance characteristics of a sensor, including its transduction characteristics and its measurement field. Also studied are algorithms for processing sensor signals to recover the characteristics of the sensor or to remove its effect in a specific measurement application. An integral part of the course is the Sensors Laboratory, which provides students with hands-on opportunities for measuring the characteristics and operational parameters of a broad range of thermo-mechanical sensors.]

[640 Experimental Mechanics
Fall. 3 credits. Not offered 1989–90.
1 lec, 1 rec, 1 lab.
This course introduces students to the principles of measurement and experimentation in mechanics, acquaints them with some of the techniques for measuring fundamental mechanical quantities, and permits them to explore experimental topics such as the elastic, viscoelastic, and plastic response of materials; the linear and nonlinear vibration of discrete and continuous systems; and acoustic and elastic wave propagation and scattering phenomena.]

655 Advanced Composite Materials and Structures
Spring. 3 credits.
Staff.
Advanced mechanics of composite materials. Strength theory of continuous and discontinuous-reinforced composites. Micromechanics, interface mechanics, modes of failure, creep-rupture. Mechanics of structural components. Design and analysis of composite structures: pressure vessels, aerospace structures, thick composites, and plates. Adhesive bonding and mechanical fastening. Dynamic effects and hygrothermal effects.

663 Solid Mechanics I
Fall. 4 credits. Corequisite: Mathematics 610.
3 lecs, 1 lab. J. T. Jenkins, W. Sachse.
Rigorous introduction to small-strain solid mechanics with emphasis on linear elasticity: stress, strain, tensors, balance laws, energy principles, general theory of linear elasticity, solutions of elementary boundary value problems.

664 Solid Mechanics II
Spring. 4 credits. Prerequisites: Mathematics 610 and T&AM 663, or equivalent.
3 lecs, 1 lab.
Preparation for advanced courses in solid mechanics. Singular solutions in linear elasticity, large deformations, nonlinear elasticity, linear visco-elasticity, mechanics of defects (cracks and dislocations), classical plasticity, and constitutive relations.

[666 Fundamentals of Acoustics
Spring. 3 credits. Not offered 1988–89.
3 lecs, biweekly labs.
Introduction to the principles and theories of acoustics. The vibrations of strings, bars, membranes, and plates; plane and spherical acoustic waves; transmission phenomena; resonators and filters; waves in solids and fluids. Application is made to sonic and ultrasonic transducers, music and noise, and architectural acoustics, and an introduction is given to the digital processing of acoustic signals. Laboratory work is required. At the level of *Fundamentals of Acoustics*, by Kinsler, Frey, Coppens, and Sanders.]

751 Continuum Mechanics and Thermodynamics
Fall. 3 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 or equivalents. Offered alternate years.
3 lecs. T. Healey.
Kinematics, conservation laws, the entropy inequality, constitutive equations, frame indifference, material symmetry. Rate-dependent materials and materials with internal variables.

[752 Nonlinear Elasticity
Fall. 3 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 or equivalents. Offered alternate years. Not offered 1989–90.
3 lecs. T. Healey.
Review of kinematics and constitutive theory appropriate for large deformations of nonlinearly elastic bodies. The basic field equations of nonlinear elastostatics and elastodynamics. Exact solutions of special problems. Linearization and stability. Nonlinear theories of thin structural members and their relationship to the three-dimensional theory. Introduction to static bifurcation theory with applications to strings, rods, plates, and shells.]

[753 Fracture
Spring. 3 credits. Prerequisites: T&AM 610 or 611; and 663 and 664 or equivalents. Offered alternate years. Not offered 1989–90.
3 lecs.
Topics will be selected from (1) elastic fracture mechanics: K, small-scale yielding, solutions of elastic crack problems; (2) nonlinear rate-independent, small-deformation fracture mechanics: plastic fracture, J-integral, small-scale yielding; (3) rate-dependent fracture mechanics: dynamic fracture, creep fracture; (4) mechanics of failure in polymers, ceramics, composites, and metals: void growth, load transfer between fibers, crazing.]

757 Inelasticity
Spring. 3 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 or equivalents. Offered alternate years.
3 lecs.
Inelasticity; plasticity, visco-elasticity, and modern nonlinear theories. Plasticity: general principles, limit analysis, and boundary value problems. Visco-elasticity: general principles and solution of boundary value problems. Modern state variable theories: their relation to classical theories, their phenomenology, and use in solving boundary value problems.

[759 Computational Methods
Fall. 4 credits. Prerequisites: T&AM 610 and 611; and 663 and 664 or equivalents. Offered alternate years. Not offered 1989–90.
3 lecs. S. Mukherjee.
The aim of this course is to survey a wide range of applications of the boundary element method (BEM) and finite element method (FEM) in solid mechanics. The boundary element method will be introduced and then be used in problems in linear elasticity, diffusion, wave propagation, and problems with material and/or geometric nonlinearities. Finite-element applications will emphasize nonlinear problems in solid mechanics.]

768 Elastic Waves
Fall. 3 credits. Prerequisites: T&AM 610 or 611; and 663 and 574 or equivalents. Offered alternate years.
3 lecs.
An advanced course on dynamic stress analysis and wave propagation in elastic solids. Theory of elastodynamics. Waves in isotropic and anisotropic media. Reflection and refraction. Surface waves and waves in layered media. Transient waves and methods of Lamb-Cagniard-Pakeris. Thick-plate theories. Vibration of spheres. Scattering of waves and dynamic stress concentration.

770 Research Topics in Solid Mechanics
Spring. 1–3 credits. Prerequisites: T&AM 610 or 611; and 663 and 664 or equivalents.
3 lecs. 1–3 faculty members.
Three topics of current research interest to faculty will be presented. The topics for each year will be posted in the late fall. Students may register for one, two, or three credits.

Dynamics and Space Mechanics

570 Intermediate Dynamics
Fall. 3 credits.
Two 1 1/4-hour lecs.
Vector and matrix methods for kinematics, Lagrangian and Newtonian mechanics for particles and rigid bodies, Euler's equations for rotating bodies, central-force motion. Small vibrations and stability. Application to robotics, gyroscopes, orbital and spacecraft dynamics.

574 Vibrations and Waves in Elastic Systems
Spring. 4 credits. Prerequisites: T&AM 570 and 610.
3 lecs, 1 lab.
Dynamics of elastic continua, including strings, membranes, and beams. Hamilton's principle, balance laws, characteristics, dispersion, phase, and group velocities.

[671 Advanced Dynamics
Spring. 3 credits. Prerequisite: T&AM 570 or equivalent. Offered alternate years. Not offered 1989–90.
Review of Lagrangian mechanics; 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.]

[672 Celestial Mechanics (also Astronomy 579)
Spring. 3 credits. Offered alternate years. Not offered 1989–90.
Two 1 1/4-hour lecs.
Description of orbits; 2-body, 3-body, and n-body problems; Hill curves, libration points and their stability; capture problems; virial theorem. Osculating elements, perturbation equations; effects of gravitational potentials, atmospheric drag, and solar radiation forces on satellite orbits; secular perturbations, resonances, mechanics of planetary rings.]

[673 Mechanics of the Solar System (also Astronomy 571)
Spring. 3 credits. Prerequisite: an undergraduate course in dynamics. Offered alternate years. Not offered 1989–90.
Two 1 1/4-hour lecs.
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.]

675 Nonlinear Vibrations
Fall. 3 credits. Prerequisite: T&AM 574 or equivalent. Offered alternate years.
Review of linear systems, free and forced vibrations. Nonlinear systems, phase plane methods, method of isoclines. Conservative systems. General autonomous systems, equilibrium and periodic solutions, linearization and Lyapunov stability criteria, Poincaré-Bendixson theorem. Quantitative analysis of weakly nonlinear systems in free and forced vibrations, perturbation methods, Krylov-Bogoliubov method. Applications to problems in mechanics.

776 Qualitative Theory of Dynamical Systems
Spring. 3 credits. Suggested prerequisite: T&AM 675, Mathematics 517, or equivalent. Offered alternate years.
Review of planar (single–degree-of-freedom) systems. Local and global analysis. Structural stability and bifurcations in planar systems. Center manifolds and normal forms. The averaging theorem and perturbation methods. Melnikov's method. Discrete dynamical systems, maps and difference equations, homoclinic and heteroclinic motions, the Smale Horseshoe and other complex invariant sets. Global bifurcations, strange attractors and chaos in free and forced oscillator equations. Applications to problems in solid and fluid mechanics.

Special Courses, Projects, and Thesis Research

[400 Science, Risk, and Public Policy (also Engr 400 and Economics 358)
Fall. 3 credits. Not offered 1989–90.
For description see Engineering Common Courses.]

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.

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.

890 Master's Degree Research in Theoretical and Applied Mechanics
Fall, spring. 1–6 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.

990 Doctoral Research in Theoretical and Applied Mechanics
Fall, spring. 1–9 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
Albright, Louis D., Ph.D., Cornell U. Assoc. Prof., Agricultural and Biological Engineering
Allmendinger, Richard, Ph.D., Stanford U. Assoc. Prof., Geological Sciences
Anantharam, Venkatachalam, Ph.D., U. of California at Berkeley. Asst. Prof., Electrical Engineering
Aneshansley, Daniel J., Ph.D., Cornell U. Assoc. Prof., Agricultural and Biological Engineering
Anton, A. Brad, Ph.D., California Inst. of Technology. Asst. Prof., Chemical Engineering
Ast, Dieter G., Ph.D., Cornell U. Prof., Materials Science and Engineering
Auer, Peter L., Ph.D., California Inst. of Technology. Prof., Mechanical and Aerospace Engineering
Avedisian, C. Thomas, Ph.D., Princeton U. Assoc. 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. Asst. Prof., Agricultural and Biological Engineering
Bassett, William A., Ph.D., Columbia U. Prof., Geological Sciences
Batterman, Boris W., Ph.D., Massachusetts Inst. of Technology. Prof., Applied and Engineering Physics
Berger, Toby, Ph.D., Harvard U. J. Preston Levis Professor of Engineering, Electrical Engineering
Bilardi, Gianfranco, Ph.D., U. of Illinois. Asst. Prof., Computer Science
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. Asst. Prof., Computer Science
Bisogni, James J., Ph.D., Cornell U. Assoc. Prof., Civil and Environmental Engineering
Blakely, John M., Ph.D., Glasgow U. (Scotland). Prof., Materials Science and Engineering
Bland, Robert G., Ph.D., Cornell U. Prof., Operations Research and Industrial Engineering
Bloom, Arthur L., Ph.D., Yale U. Prof., Geological Sciences
Bloom, Bard, Ph.D., Massachusetts Inst. of Technology. Asst. Prof., Computer Science
Bojanczyk, Adam W., Ph.D., U. of Warsaw (Poland). Asst. Prof., Electrical Engineering.
Booker, John F., Ph.D., Cornell U. Prof., Mechanical and Aerospace Engineering
Brock, Joel D. Ph.D., Massachusetts Inst. of Technology. Asst. Prof., Applied and Engineering Physics
Brown, Geoffrey M., Ph.D., U. of Texas. Asst. Prof., Electrical Engineering
Brown, Larry D., Ph.D., Cornell U. Prof., Geological Sciences
Brutsaert, Wilfried H., Ph.D., U. of California at Davis. Prof., Civil and Environmental Engineering
Buhrman, Robert A., Ph.D., Johns Hopkins U. Prof., Applied and Engineering Physics
Burns, Joseph A., Ph.D., Cornell U. Prof., Theoretical and Applied Mechanics
Cady, K. Bingham, Ph.D., Massachusetts Inst. of Technology. Prof., Nuclear Science and Engineering
Capranica, Robert R., Ph.D., Massachusetts Inst. of Technology. Prof., Electrical Engineering.
Carter, C. Barry, Ph.D., Oxford U. (England). Prof., Materials Science and Engineering
Cathles, Lawrence M. III, Ph.D., Princeton U. Prof., Geological Sciences
Caughey, David A., Ph.D., Princeton U. Prof., Mechanical and Aerospace Engineering
Chiang, Hsiao-Dong, Ph.D., U. of California at Berkeley. Asst. Prof., Electrical Engineering
Cisne, John L., Ph.D., U. of Chicago. Prof., Geological Sciences
Clancy, Paulette, Ph.D., Oxford U. (England). Asst. Prof., Chemical Engineering
Clark, David D., Ph.D., U. of California at Berkeley. Prof., Nuclear Science and Engineering
Clark, Peter A., Ph.D., Carnegie-Mellon U. Asst. Prof., Chemical Engineering
Cohen, Claude, Ph.D., Princeton U. Prof., Chemical Engineering
Coleman, Thomas F., Ph.D., U. of Waterloo. Assoc. Prof., Computer Science
Compton, Richard C., Ph.D., California Inst. of Technology. Asst. 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
Datta, Ashim K., Ph.D., U. of Florida. Asst. 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. Asst. Prof., Civil and Environmental Engineering
Delchamps, David F., Ph.D., Harvard U. Assoc. Prof., Electrical Engineering
Derksen, Richard C., Ph.D., U. of Illinois. Asst. Prof., Agricultural and Biological Engineering
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
Donald, Bruce, Ph.D., Massachusetts Inst. of Technology. Asst. Prof., Computer Science
Duncan, Michael, Ph.D., California Inst. of Technology. Asst. Prof., Chemical Engineering
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