College of Engineering

Administration

Thomas E. Everhart, dean
Donald F. Berth, associate dean
Malcolm S. Burton, associate dean
William B. Streett, associate dean
Benjamin Nichols, assistant dean and director of Division of Basic Studies
Ron W. Simmons, assistant dean
Gilbert F. Rankin, director of administrative operations and facilities
Robert E. Gardner, director of admissions
Mariea T. Blackburn, associate director of admissions
Robert L. Smith, assistant director of admissions
Gladys J. McConkey, director of engineering publications
Jane H. Pirko, registrar
Carol A. Walck, director of placement

Facilities

Most of the academic units of the College of Engineering are centered in the ten modern buildings located on the Engineering Quadrangle. Facilities for applied and engineering physics are located in Clark Hall on the College of Arts and Sciences campus.

Special facilities used in engineering include the following:

Computer-Aided Design Instructional Facility (CADIF). A new laboratory providing state-of-the-art computer graphics technology for engineering course work.

Cornell Computing Facility. A central IBM 370/168 system, a DEC system 2060, satellite stations, and interactive terminals.

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

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

Materials Science Center. Provides highly sophisticated equipment for interdisciplinary research.

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

National Research and Resource Facility for Submicron Structures. An interdisciplinary facility centered in the School of Electrical Engineering.

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

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.

Graduate programs, which are administered by the Graduate School, are described in the *Announcement of the Graduate School* and the special Announcement *Graduate Study in Engineering and Applied Science.* Two programs that are closely related to undergraduate study in the College of Engineering—the Master of Engineering degree program and a special master's degree program that combines studies in engineering and in business administration—are described below.

The Master of Engineering Degree Program

One-year Master of Engineering (M.Eng.) programs are offered in eleven 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 eleven Master of Engineering degrees, and the academic areas 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 science

M.Eng. (Electrical): Electrical engineering

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

M.Eng. (OR&IE): Operations research and industrial engineering

M.Eng. (Materials): Materials science and engineering

M.Eng. (Mechanical): Mechanical and aerospace engineering

M.Eng. (Nuclear): Nuclear science and engineering

Cornell engineering graduates in the upper half of their class will generally be admitted to the program; however, requirements for admission vary by field. Other applicants must have a baccalaureate degree from an engineering program accredited by the Accreditation Board for Engineering and Technology or its equivalent, 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. Application forms and further information are available from the chairperson of the Graduate Professional Programs Committee, Hollister Hall.

Cooperative Program with the Graduate School of Business and Public Administration

A dual program culminating in both Master of Engineering and Master of Business Administration degrees is available for students with suitable undergraduate background. The curriculum generally requires two years of study beyond the baccalaureate, rather than the three years such a program would normally require; with appropriate choice of undergraduate courses, it is possible to earn the Bachelor of Science, the Master of Engineering, and the Master of Business Administration degrees in six years.

Students interested in this special program should plan their undergraduate curricula with this in mind. Advice and information should be sought from the undergraduate engineering department in which the student is taking an upperclass field program. Information about admission to the graduate program and about special scholarship aid that is available may be obtained from the Graduate Professional Programs Committee, Hollister Hall.

Undergraduate Study

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

Agricultural engineering*

Chemical engineering

Civil and environmental engineering

College program

Computer science

Electrical engineering

Engineering physics

Geological sciences

Materials science and engineering

Mechanical engineering

Operations research and industrial engineering

Students in the College of Engineering begin their undergraduate curriculum in the Division of Basic Studies. 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 studies adapted to individual interests.

A student interested in bioengineering may arrange a suitable curriculum within one of the field programs or through the College Program. Information about options is available in the Engineering Advising and Counseling Center, 167 Olin Hall.

The undergraduate curriculum in engineering was revised in 1981. Students belonging to the class of 1984 and earlier classes must complete their studies according to the course program in effect at the time of their matriculation. The upperclass program with which these students should now be affiliated is, in most cases, a field program beginning in their junior year. Such a field program requires twelve field-designated courses, four liberal-studies electives, two free electives, and two technical electives. The overall degree requirement is forty courses totalling at least 127 credits.

Under this course program, the four-year curriculum includes at least eight liberal-studies courses giving a minimum of 24 credits. These liberal-studies electives may include courses in the humanities, social sciences, modern foreign languages, and expressive arts; at least two (giving a minimum of 6 credits) must be at the upperclass level (300- or 400-level courses).

Students of the class of 1985 and subsequent classes must fulfill the requirements for graduation outlined below.

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

Requirements for Graduation

To receive the Bachelor of Science degree, students must meet the requirements of the Common Program, as set forth by the College of Engineering, as well as the requirements of the field program, as established by the school or department with which they become affiliated. The Common Program is composed of courses in eight categories.

Type of course	*Credits*
1) Mathematics	15
2) Physics	12
3) Chemistry	4
4) Freshman Seminar	6
5) Computing: computer programming plus one approved course in computing applications	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

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 128 and 140. 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 or 193, 192, 293, and 294. Students who have little or no acquaintance with the calculus take Mathematics 191. Students with some knowledge of the calculus, but not enough for advanced placement, take Mathematics 193.

Physics

The normal program in physics includes Physics 112, 213, and 214. Students in the Field Program in Civil and Environmental Engineering may substitute Chemistry 208 for Physics 214.

Chemistry

Chemistry 207 is required for all students and is normally taken in the first freshman semester.

Freshman Seminars

Each semester of their freshman year, students choose a Freshman Seminar from among more than fifty courses offered by over a dozen different departments in the humanities, social sciences, and expressive arts. These courses all 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 105, Introduction to Computer Programming. Before graduation, they must take an additional course with a significant amount of computing applications. Courses that satisfy this requirement are Engr 211, Engr 321, CEE 301, EE 624, MAE 489, MAE 570, and MAE 575.

Engineering Distribution

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

1) *Scientific computing*
   Engr 211, Computers and Programming
   Engr 321, Numerical Methods

Students in the Field Program in Civil and Environmental Engineering may substitute CEE 301 for Engr 321.

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 Applied and 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 Ele E 310 for Engr 260. Students in the Field Program in Applied and Engineering Physics may substitute Ele E 310 or Mathematics 471 for Engr 260.

5) *Electrical sciences*
   Engr 210, Introduction to Electrical Systems

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

7) *Introduction to engineering*
   Several courses are offered each year to introduce freshmen to the various fields of engineering. These courses, which are numbered consecutively beginning with Engr 110, are not included in this Announcement. A separate list will be made available.

Humanities and Social Sciences

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

The contents of these categories are listed below. At least three courses must be chosen from category (a), and no more than one course may be chosen from category (c).

a) Humanities or History
This category includes all courses designated by the College of Arts and Sciences as fulfilling its distribution requirements in humanities and history (see pp. 91–92), as well as the following:

History of Art: all courses numbered 200 and above;
Music: all introductory courses (except 122) and all theory and history courses;
Theater Arts: all history, literature, and theory courses, and all cinema courses except 377 and 477.

b) Social Sciences
This category includes all courses designated by the College of Arts and Sciences as fulfilling its distribution requirements in social sciences (see p. 91), as well as the following:

College of Agriculture and Life Sciences: Agricultural Economics 150, 250, 332; Communication Arts 200, 215, 302, 303, 404; Education 110, 271, 317; Natural Resources 201, 407; Rural Sociology, all courses.
College of Architecture, Art, and Planning: Architecture 141, 142, 343, 545; City and Regional Planning 340, 400, 402, 403, 404, 413, 414.
College of Arts and Sciences: Economics, all courses except 317, 318, 319, 320.
College of Engineering: Civil and Environmental Engineering 321, 322, 325; Computer Science 305; Mechanical and Aerospace Engineering 302.
School of Hotel Administration: 111, 281, 282.
College of Human Ecology: Consumer Economics and Housing 110, 111, 148, 247, 355; Human Development and Family Studies, all courses except 141, 242, 243, 348.
School of Industrial and Labor Relations: All courses except those in economic and social statistics.
Division of Nutritional Sciences 115.

c) Expressive or Communication Arts
This category includes all courses designated by the College of Arts and Sciences as fulfilling its distribution requirements in expressive arts (see p. 92), as well as the following:

College of Agriculture and Life Sciences: Communication Arts, all courses; Floriculture 111.
College of Architecture, Art, and Planning: Art, all courses.
College of Arts and Sciences: All language courses.
College of Human Ecology: Design and Environmental Analysis 101, 111, 115.

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. Free electives 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. Each field maintains a list of courses suggested as approved and technical electives.

Division of Basic Studies

All students are enrolled in the Division of Basic Studies during their freshman year. They remain in this division until they enter a field program or the College Program. Engineering courses taken at this level are listed under Engineering Common Courses.

Following is a typical curriculum for freshmen. Many variations are possible, depending on the individual student's background, advanced placement credit, and career goals. Those acquainted with the calculus may take Physics 112 in term one. Students who intend to enter the Field Program in Chemical Engineering should take Chemistry 208 in term two as an approved elective. Students with an interest in bioengineering may take biology in terms one and two as approved electives.

Term 1	*Credits*
Math 191 or 193, Calculus for Engineers	4
Chem 207, General Chemistry	4
Engr 105, Introduction to Computer Programming; or Physics 112, Mechanics and Heat	3
Introduction to Engineering, or an approved elective	3
Freshman Seminar	3
Term 2	
Math 192, Calculus for Engineers	4
Phys 112, Mechanics and Heat; or Physics 213, Electricity and Magnetism	4
Approved elective or Engr 105, Introduction to Computer Programming	3 or 4
Engineering distribution course, humanities and social sciences course, or approved elective	3 or 4
Freshman 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 may choose to enroll in a field program at the beginning, middle, or end of their sophomore year. Some fields require a specific engineering distribution course as a prerequisite for the upperclass course sequence. These are:

Applied and Engineering Physics: Engr 221
Chemical Engineering: Engr 219
Civil and Environmental Engineering: Engr 202
Computer Science: Engr 211
Electrical Engineering: Engr 210
Mechanical and Aerospace Engineering: Engr 202
Operations Research and Industrial Engineering: Engr 260

College Program

Individually arranged courses of study under the College Program are possible for those 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 may receive 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.

Every curriculum in the College Program, with the exception of certain faculty-sponsored programs, must comprise an engineering major and a 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 fourteen courses in the major and minor subjects, including at least seven engineering courses, each program includes humanities and social sciences electives and free electives.

Further information about the College Program may be obtained from the College Program Office, 253 Carpenter Hall.

Dual Degree Option

A special academic option, intended for superior students, is the dual degree program, in which both Bachelor of Science and Bachelor of Arts degrees can be earned in five years. Students registered in either 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 Associate Dean M. S. Burton, 253 Carpenter Hall.

Engineering Cooperative Program

A special program for undergraduates in most fields of engineering is the Engineering Cooperative Program, which provides an opportunity to supplement course work with carefully monitored, paid jobs in industry and other engineering-related enterprises. Sophomores in the upper half of their class are eligible to apply for the program; students from foreign countries must have visas that allow them to work in the United States.

Prospective co-op students 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 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 classmates.

Further information may be obtained from the Engineering Cooperative Program office, 105 Hollister Hall.

Advanced Placement Credit

A growing number of freshmen entering the College of Engineering are eligible to receive advanced placement (AP) credit toward degree requirements, in recognition of demonstrated academic proficiency. 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 academic credit is intended to permit students to develop more challenging and stimulating programs of study. Two ways in which freshmen may use such credit are detailed below.

1) AP credit can be used to fulfill basic requirements, thus permitting advanced study in the same subject area or enrollment in additional nontechnical elective courses.

2) In a few cases, students may receive enough AP credit to complete the B.S. degree requirements ahead of time.

The college's policies concerning placement credit and its use in developing undergraduate programs are fully described in the publication *Advanced Placement for Engineers,* which may be obtained at the Division of Basic Studies, 167 Olin Hall, or the Engineering Admissions Office, 221 Carpenter Hall.

Transfer Credit

Entering freshman 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.

College courses completed under the auspices of cooperative college—high school programs may be considered for an exception to these general policies concerning advanced standing. Credit for such courses is not automatically given, however; students must be prepared to demonstrate academic proficiency by taking the appropriate CEEB or Cornell departmental placement examination, as described above.

Academic Standing

The requirements for good standing in the college vary slightly among the different divisions. Freshmen must have a grade-point average of 1.7 or higher with no failing, unsatisfactory, or incomplete grades. Sophomore requirements are the same, except that the grade-point average must be at least 2.0. Upperclass requirements depend upon the field of registry.

Dean's List citations are presented each semester to those engineering students with exemplary academic records. The criteria for this honor are determined by the dean of the college. In 1981–82 a term average of 3.25 or higher was required, with no failing, unsatisfactory, or incomplete grades, and 12 credits or more of letter grades.

Agricultural Engineering

N. R. Scott, chairman; L. D. Albright, J. A. Bartsch, J. R. Cooke, R. B. Furry, W. W. Gunkel, D. A. Haith, L. H. Irwin, W. J. Jewell, G. Levine, R. C. Loehr, H. A. Longhouse, D. C. Ludington, W. F. Millier, R. E. Pitt, G. E. Rehkugler, L. P. Walker, M. F. Walter

Bachelor of Science Curriculum

Students in the Field Program in Agricultural Engineering are usually enrolled in the College of Agriculture and Life Sciences during the freshman and sophomore years, and jointly enrolled in that college and the College of Engineering in the junior and senior years (paying the engineering college tuition in the junior year). The curriculum is outlined below.

Basic Subjects	*Credits*
Math 191, 192, 293, 294, Calculus and Engineering Mathematics	15
Chem 207, General Chemistry	4
Phys 112, 213, 214, Physics I, II, and III	12
Introductory biological sciences	6 to 8
Ag Eng 151, 152, Computer Programming and Graphics	4
Engineering distribution (four courses, including Mechanics of Solids, Thermodynamics, Computers and Programming)	12
Humanities and social sciences (eight courses, including two in written expression, one in oral expression, and a minimum of 9 credits in humanities)	24
Advanced and Applied Subjects	
Engineering sciences (Fluid Mechanics; Dynamics; Ag Eng 153; Ag Eng 250; and four agricultural engineering courses above 450 (for a minimum of 12 credits), excluding seminar or special-problems courses	33
Biological or agricultural sciences	12
Free electives	6
Total credits	128 to 130

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 rather than for those who expect to study for the doctorate. The curriculum is planned as an extension of the Cornell undergraduate program in agricultural engineering but can accommodate graduates of other engineering programs. 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 thirty credits consist of an engineering design project that culminates in a professional-level 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) power and machinery, (b) soils and water engineering, (c) agricultural structures and associated systems, (d) electric power and processing, (e) energy management, (f) agricultural waste management, (g) bioengineering, (h) secondary-road design and construction, and (i) food engineering. Engineering electives are chosen from among subject areas relevant to agricultural engineering, such as thermal engineering, mechanical design and analysis, theoretical and applied mechanics, structural engineering, hydraulics, environmental engineering, soil engineering, waste management, and electronics.

Applied and Engineering Physics

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

The engineering physics curriculum is designed for students who want to pursue careers in research or development in applied science or advanced technology. Its distinguishing feature is a focus on fundamentals, both experimental and theoretical, that have broad applicability in engineering and in science.

The industrial demand for baccalaureate graduates is high, and many students go directly into industrial positions. However, most graduates go on to advanced study in a variety of fields, including astrophysics, atmospheric sciences, biophysics, chemical physics, energy conversion, environmental science, geophysics, materials science and engineering, nuclear engineering, nuclear physics, oceanography, plasma physics, quantum optics, optics, and solid-state electronics.

Underclass students who are planning to enter the Field Program in Engineering Physics are encouraged to register in honors sections of mathematics during the first two years. Those who matriculate in the college with advanced standing in mathematics may take Physics 112 in the fall term of their freshman year and Applied Mathematics* in the spring term of their sophomore year. A course in thermodynamics is required for entry into the program. Engr 221, taken as an engineering distribution course, will satisfy this requirement. A&EP 333 (Mechanics of Particles and Solid Bodies) is an approved upperclass substitute for Engr 203, the engineering distribution course in dynamics, but students who place out of Physics 112 (Mechanics and Heat) may still wish to take Engr 203. Mathematics 471 (Basic Probability) or Ele E 310 (Probability and Random Signals) may be substituted for Engr 260, the engineering distribution course in probability. Finally, students in engineering physics wishing to take an engineering distribution course in computer science are urged to take Engr 321 (Numerical Methods).

A judicious choice of approved electives during the freshman and sophomore years can open up valuable opportunities later on. Examples include Chemistry 208 and Engr 110 for students with an interest in chemical physics, Geol 101 for students with an interest in geophysics, A&EP 217 for students with an interest in energy, or A&EP 206 for students with an interest in biophysics or medicine. Students with other interests are encouraged to seek advice from A&EP faculty.

The following curriculum is a typical upperclass field program.

Term 5	*Credits*
A&EP 333, Mechanics of Particles and Solid Bodies	4
A&EP 355, Intermediate Electromagnetism	4
Applied Mathematics I*	4
Free elective	3 or 4
Liberal studies elective	3 or 4
Term 6	
A&EP 361, Introductory Quantum Mechanics	4
A&EP 356, Intermediate Electrodynamics	4
Applied Mathematics II*	4
Electronic Circuits†	3 or 4
Liberal studies elective	3 or 4
Term 7	
A&EP 423, Statistical Thermodynamics	4
Phys 410, Advanced Experimental Physics	4
Applied Mathematics III*	4
Technical elective	3 or 4
Liberal studies elective	3 or 4
Term 8	
A&EP 434, Continuum Physics	4
Applications of Quantum Mechanics‡	3 or 4
Free elective	3 or 4
Technical elective	3 or 4
Liberal studies elective	3 or 4

*Applied Mathematics I and II may be either Mathematics 421–422 or T&AM 610–611. Applied Mathematics III may be Mathematics 423, T&AM 613–614, or another mathematics course such as Mathematics 411, 427, or 471. Alternate courses will be considered upon petition.

†Electronic Circuits may be A&EP 363 or an equivalent junior-level electronics course.

‡A choice of the following courses may be made: Physics 454, Introductory Solid-State Physics; Physics 444, Nuclear and High-Energy Particle Physics; A&EP 609, Low-Energy Nuclear Physics (fall); Electrical Engineering 731, Quantum Electronics I (fall).

Considerable flexibility is possible in the scheduling of these courses. For example, Physics 410 may be taken in term seven or in term eight. Quantum mechanics can be studied in term six as A&EP 361 or in term seven as Physics 443. The course in applications of quantum mechanics can be taken whenever the appropriate prerequisite has been met. If scheduling conflicts arise, the school may allow substitutions 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; and a number of advanced courses in fluid mechanics or elasticity are similar to A&EP 434.

Free and technical electives need not be all formal course work; qualified students may undertake informal study under the direction of a member of the faculty. This may include research projects in areas in which faculty members are active. These areas include electron microscopy and diffraction, quantum electronics, solid-state and surface physics, atomic physics, geophysics, biophysics, nuclear structure physics, nuclear engineering, and plasma physics. 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 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 specific required courses, and to attain each term an overall grade-point average of a least 2.3.

Areas of concentration. An area of concentration in an interdisciplinary study such as biophysics, geophysics, nuclear engineering, lasers and quantum electronics, or plasma physics and materials science may be arranged through a judicious choice of electives in the freshman and sophomore as well as the upperclass years. Examples of many such programs are described in a special brochure available from the School of Applied and Engineering Physics, Clark Hall. Students interested in this kind of program are advised to consult as early as possible a professor active in the field of interest or with the associate director of the school, Prof. A. F. Kuckes.

Master of Engineering (Engineering Physics) Degree Program

The Master of Engineering (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 specific area such as microfabrication or physical instrumentation. A wide latitude is allowed in the choice of the required design project.

Each individual program is planned by the student in consultation with the program chairman. 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 engineering physics or 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 shall 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 chairman, is carried out on an individual basis under the guidance of a member of the engineering 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 correlated 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.

Chemical Engineering

J. C. Smith, director; G. F. Scheele, assistant director; J. F. Cocchetto, C. Cohen, R. K. Finn, K. E. Gubbins, P. Harriott, R. P. Merrill, W. L. Olbricht, F. Rodriguez, M. L. Shuler, P. H. Steen, W. B. Streett, R. G. Thorpe, R. L. VonBerg, H. F. Wiegandt

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 biological 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	3
Phys 213, Physics II	4
Chem 287–289, Physical Chemistry (approved elective)	5
Chem E 219 (engineering distribution course)	3
Humanities or social sciences elective	3

Term 4	
Math 294, Engineering Mathematics	4
Phys 214, Physics III	4
Chem 288–290, Physical Chemistry	5
Engineering distribution course*	3
Humanities or social sciences elective	3
Term 5	
Chem 357, Organic Chemistry†	3
Chem 251, Organic Chemistry Laboratory	2
Chem E 311, Chemical Engineering Thermodynamics I	3
Chem E 430, Introduction to Rate Processes	3
Elective‡	3
Liberal studies elective**	3
Term 6	
Chem 358, Organic Chemistry†	3
Chem E 312, Chemical Engineering Thermodynamics II	3
Chem E 431, Analysis of Separation Processes	3
Elective‡	3
Liberal studies elective**	3
Term 7	
Chem E 101, Nonresident Lectures	0
Chem E 410, Reaction Kinetics and Reactor Design	3
Chem E 432, Chemical Engineering Laboratory	3
Chem E 461, Chemical Process Evaluation	3
Elective‡	3
Liberal studies elective**	3
Term 8	
Chem E 462, Chemical Process Synthesis	4
Chem E 671, Process Control	3
Electives‡	
Classes of '83 and '84	6
Classes of '85 and after	3
Liberal studies elective**	3

*It is recommended that Engr 211 or 321 be taken as one of the engineering distribution courses, since it will also satisfy the requirement of an additional course in computing applications.

†Students in the Engineering Cooperative Program substitute Chem 253, Organic Chemistry (a 4-credit course), for Chem 357; and Chem E 421, Industrial Organic Processes (a 2-credit course), for Chem 358.

‡The electives in terms five through eight comprise 6 credits of technical electives and 6 credits of free electives. In addition, for students of the classes of 1983 and 1984, the electives include 3 credits of the postponed engineering core science course (as described in the 1981–82 *Courses of Study*).

**Liberal studies elective for classes of 1983 and 1984 is humanities or social sciences elective for class of 1985 and later.

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 process, equipment, and plant design alternatives. A design project is involved in the required courses. General admission and degree requirements are described in the college's introductory section.

Civil and Environmental Engineering

School of Civil and Environmental Engineering: R. N. White, director; J. J. Bisogni, associate director

Department of Structural Engineering: A. H. Nilson, chairman; J. F. Abel, P. Gergely, M. D. Grigoriu, A. R. Ingraffea, I. Ishibashi, F. H. Kulhawy, W. McGuire, T. D. O'Rourke, T. Peköz, F. O. Slate, R. N. White

Department of Environmental Engineering: A. H. Meyburg, chairman; J. J. Bisogni, W. H. Brutsaert, R. I. Dick, L. B. Dworsky, G. P. Fisher, J. M. Gossett, D. A. Haith, G. H. Jirka, J. A. Liggett, L. W. Lion, P. L. -F. Liu, R. C. Loehr, D. P. Loucks, W. R. Lynn, N. Orloff, R. E. Schuler, C. Shoemaker, J. R. Stedinger, M. A. Turnquist

Program in Environmental Sensing, Measurement, and Evaluation: T. Liang, G. B. Lyon, W. R. Philipson

Bachelor of Science Curriculum

The School of Civil and Environmental Engineering contains two departments as well as the Program in Environmental Sensing, Measurement, and Evaluation. Undergraduate specialties can be arranged in a number of subject areas encompassed by these units. The Department of Structural Engineering offers instruction in analysis, behavior, and design of structures; structural materials; and geotechnical engineering. Within the Department of Environmental Engineering there are five subject areas: environmental quality engineering; fluid mechanics and hydrology; public systems and environmental systems engineering; transportation; and water resources planning and analysis.

Students planning to enter the Field Program in Civil and Environmental Engineering are required to take Mechanics of Solids (Engr 202) during the sophomore year. It is recommended that they also take Introductory Engineering Probability (Engr 260) and either Dynamics (Engr 203) or Mechanical Properties of Materials (Engr 261). These three courses are required in the field program.

At the upperclass level the curriculum is planned to provide an introduction to the several diverse areas within the field of civil and environmental engineering and to permit more-detailed study in at least one area through appropriate selection of electives. A recommended sequence, including the required courses, is given below.

Term 5	*Credits*
Engr 203, Dynamics*	3
CEE 331, Fluid Mechanics I	4
CEE 371, Structural Engineering I	4
Engr 260, Introductory Engineering Probability*	3
Liberal studies elective	3
Term 6	
Engr 261, Introduction to Mechanical Properties of Materials	3
CEE 351, Environmental Quality Engineering	4
CEE 341, Introductory Soil Mechanics	3
CEE 323, Engineering Economics and Systems Analysis	3
Liberal studies elective	3
Term 7	
Civil and environmental engineering distribution courses (2 courses)†	6
Technical elective	3
Free elective	3
Liberal studies elective	3
Term 8	
Civil and environmental engineering distribution courses (2 courses)†	6
Technical elective	3
Free elective	3
Liberal studies elective	3

*Satisfactory completion of these engineering core science courses in the Division of Basic Studies increases the number of technical electives accordingly.

†Information about distribution requirements may be obtained from the student's faculty adviser.

Master of Engineering (Civil) Degree Program

The Master of Engineering (Civil) degree program is designed to prepare a student for professional practice in civil and environmental engineering. Requirements, in addition to the general ones for the degree (see the introductory section under College of Engineering), include three required courses: one in professional engineering practice and two in design (CEE 501 and 502). The design sequence requires the completion of a project involving synthesis, analysis, decision making, and application of engineering judgment, and includes an intensive, full-time, three-week session between semesters.

The remainder of a 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. The objectives in course planning are to provide breadth in the fundamentals of civil and environmental engineering, and specialization in one area with some concentration in a related area. Most students will have achieved the necessary breadth during their undergraduate years. Some, however, may require additional course work in the graduate program to fulfill the breadth requirement. Students in the School of Civil and Environmental Engineering may avail themselves of a number of graduate course offerings in fields related to their major interest but outside of the school.

The School of Civil and Environmental Engineering, in conjunction with the Cornell Graduate School of Business and Public Administration, now offers a six-year, joint program leading to the degrees of Bachelor of Science, Master of Engineering, and Master of Business Administration. Participating students receive the baccalaureate degree after four years and the two professional master's degrees in the next two years.

Applications should be submitted at the beginning of the sixth term of study.

Computer Science

B. Aspvall, Ö. Babaoğlu, T. Coleman, R. L. Constable, R. W. Conway, A. J. Demers, J. R. Gilbert, D. Gries, J. Hartmanis, J. E. Hopcroft, F. Luk, P. A. Pritchard, G. Salton, F. B. Schneider, D. Skeen, R. Teitelbaum, S. Toueg, C. F. Van Loan

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. Those interested in the application of computers in some particular area are ordinarily advised to major in the area of application and take elective course work in computer science.

A student entering the Field Program in Computer Science must take Com S 211 and a fourth-term mathematics course approved in the Engineering Common Program before beginning the upperclass sequence. 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	8
Com S 314, Systems and Organization	
Com S 410, Data Structures	
Theory sequence	12
Com S 280, Discrete Structures	
Com S 481, Theory of Computing	
Com S 482, Analysis of Algorithms	
Numerical analysis	4
Com S 321, Numerical Methods	
Computer science electives	8
Any nonrequired computer science courses numbered above 410	
Related electives	12
One mathematically oriented course plus three courses forming a coherent sequence in operations research, electrical engineering, or another technical area	
Core science	3
Ele E 230	
Technical or free electives	15
Liberal studies electives	12

Master of Engineering (Computer Science) Degree Program

A recent addition to the academic offerings in computer science is the one-year program leading to the degree of Master of Engineering (Computer Science). The program is very small; from two to five students a year are admitted. Admission standards are the same as those applied to doctoral candidates. A good undergraduate background in mathematics or computer science is required.

In the curriculum, the emphasis can be on programming languages and systems, on theory of algorithms and theory of computation, on numerical analysis, or on information processing, which includes data bases 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

J. M. Ballantyne, director; J. L. Rosson, associate director; T. Berger, R. Bolgiano, Jr., N. H. Bryant, R. R. Capranica, H. J. Carlin, G. C. Dalman, D. F. Delchamps, L. F. Eastman, T. E. Everhart, D. T. Farley, T. L. Fine, J. Frey, T. Hagfors, C. Heegard, W. J. Heetderks, C. R. Johnson, Jr., M. C. Kelley, M. Kim, P. M. Kintner, J. R. Krusius, W. H. Ku, C. A. Lee, R. L. Liboff, S. Linke, H. S. McGaughan, P. R. McIsaac, J. A. Nation, B. Nichols, C. Pottle, C. E. Seyler, Jr., R. N. Sudan, C. L. Tang, R. J. Thomas, J. S. Thorp, H. C. Torng, N. M. Vrana, 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 areas in addition to specialization in one or more.

Students can choose, for example, to concentrate in bioengineering; computer engineering; control systems; electronic circuit design; information, communications, and decision theory; microwave electronics; plasma physics; power and energy systems; quantum and optical electronics; radio and atmospheric physics; or semiconductor devices and applications.

In addition to courses for completion of the Common Program requirements, the electrical engineering Bachelor of Science curriculum requirements are as follows:

Course	*Credits*
Ele E 210, Introduction to Electrical Systems*	3
Ele E 230, Introduction to Digital Systems†	3
Ele E 301, Electrical Signals and Systems I	4
Ele E 303, Electromagnetic Theory I	4
Ele E 306, Fundamentals of Quantum and Solid-State Electronics	4
Ele E 315, Electrical Laboratory I	4
Ele E 316, Electrical Laboratory II	4
Electrical engineering electives (at least 6)‡	19
	45**

*Engineering distribution course.

†Satisfactory completion of Ele E 230 as an approved elective permits the substitution of a technical elective for this requirement.

‡Of the six electrical engineering electives, two courses must be selected from Ele E 302, 304, 310, or 435. Two must be laboratory courses.

**Credits in excess of 45 may be used to fulfill approved, technical, or free elective requirements of the common program.

Specialization is achieved through the four senior-year electrical engineering electives, which are selected from more than sixty offerings of the school.

A brochure describing the field program and concentrations in detail may be obtained from the School of Electrical Engineering, Phillips Hall.

Master of Engineering (Electrical) Degree Program

The degree of Master of Engineering (Electrical) prepares the student either for professional work in this area of engineering or for more advanced graduate study in the doctoral program. The Master of Engineering differs from the Master of Science degree program mainly in its emphasis, which is on design capability rather than basic research. The 30-credit curriculum includes two two-term course sequences in electrical engineering, and the design project, which alone may account for 3 to 10 credits. General admission and degree requirements are described in the college's introductory section.

Geological Sciences

D. L. Turcotte, chairman; S. B. Bachman, W. A. Bassett, J. M. Bird, A. L. Bloom, L. D. Brown, J. L. Cisne, A. K. Gibbs, B. L. Isacks, D. E. Karig, S. Kaufman, R. W. Kay, J. E. Oliver, F. H. T. Rhodes, W. B. Travers

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 should take certain courses during their freshman and sophomore years. These are Geo 101 and 102, Chemistry 208, and, for those interested in geobiology, Biological Sciences 101–103 and 102–104. The usual upperclass curriculum for students entering the field as juniors is listed below. Students entering as sophomores must meet the same basic field requirements.

Term 5	*Credits*
Geol 355, Mineralogy	4
Geol 376, Sedimentology and Stratigraphy	4
Required science course	3 or 4
Liberal studies elective	3
Technical or free elective	3 or 4
Term 6	
Geol 356, Petrology and Geochemistry	4
Geol 325, Structural Geology	4
Required science course	3 or 4
Liberal studies elective	3
Geol 704, Western Field Course	6
or	
Technical or free elective	3 or 4

A summer field course is required unless approval for an alternative field experience is granted.

Term 7	
Geology elective, 300 or 400 level	3 or 4
Required science course	3 or 4
Liberal studies elective	3
Technical or free elective	3 or 4
Term 8	
Geol 388, Geophysics and Geotectonics	4
Required science course	3 or 4
Liberal studies elective	3
Technical or free elective	3 or 4
Free elective	3 or 4

Students intending to specialize in *geophysics* should select their *required sciences* from the following courses or their equivalents:

Math 421–422–423, Applicable Mathematics
T&AM 310–311, Advanced Engineering Analysis I and II
A&EP 355, Intermediate Electromagnetism
A&EP 333, Mechanics of Particles and Solid Bodies
A&EP 356, Intermediate Electrodynamics
A&EP 434, Continuum Physics
Phys 410, Advanced Experimental Physics
T&AM 450, Introduction to Continuum Mechanics

Students intending to specialize in *geochemistry* (including petrology and minerology) should select their *required sciences* from the following courses or their equivalents:

Chem 287–288, Introductory Physical Chemistry
Chem 300, Introductory Quantitative Analysis
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, Structure and Properties of Materials
MS&E 335, Thermodynamics of Condensed Systems

Students intending to specialize in *geobiology* should select their *required sciences* from the following courses or their equivalents:

Bio S 212, Invertebrate Zoology
Bio S 330–331, Principles of Biochemistry
Bio S 241, Plant Biology
Bio S 448, Plant Evolution and the Fossil Record
Bio S 360, General Ecology
Bio S 274, The Vertebrates
Bio S 477, Organic Evolution
Bio S 281, Genetics
Chem 253, Elementary Organic Chemistry

Students who want to pursue further training or immediate employment in *applied geology* (environmental and engineering geology, ground water, petroleum geology, or geological engineering) should select their *required sciences* from the following courses or their equivalents, with two of the four from the same field:

Agron 301, Identification, Appraisal, and Geography of Soils
Agron 701, Soil Chemistry
Agron 607, Soil Physics
CEE 341, Introductory Soil Mechanics
CEE 640, Foundation Engineering
CEE 612, Physical Environment Evaluation
MS&E 331, Structure and Properties of Materials
MS&E 445, Mechanical Properties of Materials
CEE 331, Fluid Mechanics
CEE 332, Hydraulic Engineering
CEE 351, Environmental Quality Engineering
Math 421–422–423, Applicable Mathematics
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 taking economics courses as liberal studies electives and should select their *required sciences* from the group of courses composed of those 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 the four required science courses from the same field, and all four required science courses must be at the 300 level or above. The technical electives may be chosen from offerings in geological sciences or in other science or engineering fields, and may be courses also approved as required sciences. Outstanding students may request substitution of an honors thesis for a fourth-year technical elective.

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

Materials Science and Engineering

A. L. Ruoff, director; D. G. Ast, J. M. Blakely, C. B. Carter, D. T. Grubb, E. W. Hart, H. H. Johnson, D. L. Kohlstedt, E. J. Kramer, C. Y. Li, J. W. Mayer, R. Raj, S. L. Sass, D. N. Seidman

Bachelor of Science Curriculum

Students who major in materials science and engineering are required to take Engr 261, Introduction to Mechanical Properties of Materials, before the end of their junior year. They are strongly urged to take it as part of the engineering distribution course requirement during their freshmen or sophomore year. The usual upperclass curriculum for students entering the field as juniors is listed below. Students entering as sophomores must meet the same basic field requirements.

Term 5	*Credits*
MS&E 331, Structure and Properties of Materials	4
MS&E 333, Research Involvement I or a field-approved option elective*	3
MS&E 335, Thermodynamics of Condensed Systems	3
Free elective	3
Liberal studies elective	3
Term 6	
MS&E 332, Electrical and Magnetic Properties of Materials	3
MS&E 334, Research Involvement II or a field-approved option elective*	3
MS&E 336, Kinetics, Diffusion, and Phase Transformation	3
Free elective	3
Liberal studies elective	3
Term 7	
MS&E 441, Microprocessing of Materials	3
MS&E 443, Senior Materials Laboratory I	3
MS&E 445, Mechanical Properties of Materials	3
Technical elective	3
Liberal studies elective	3
Term 8	
MS&E 442, Macroprocessing of Materials	3
MS&E 444, Senior Materials Laboratory II	3
MS&E 446, Current Topics in Materials	3
Technical elective	3
Liberal studies elective	3

Master of Engineering (Materials) Degree Program

Students who have completed a four-year undergraduate program in engineering or the physical sciences are eligible for consideration for admission to the M.Eng. (Materials) program, which includes the following:

1) A project qualifying for at least 12 credits and requiring individual effort and initiative. This project, carried out under the supervision of a member of the faculty, is usually experimental, although it can be analytical.
2) Six credits of courses in mathematics or applied mathematics. This requirement may be satisfied by courses T&AM 310 and 311; students who have previously completed these must select other courses acceptable to the faculty.
3) Courses in materials science and engineering selected from any of those offered at the graduate level or other courses approved by the faculty, required to bring the total credits to 30.

General admission and degree requirements are described in the introductory section under "College of Engineering."

*The research involvement option gives undergraduates the opportunity to work with faculty members and their research groups on current projects. The alternative-option elective provides students interested in industrial careers an additional opportunity to broaden their engineering education.

Mechanical and Aerospace Engineering

A. R. George, 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, F. C. Gouldin, S. Leibovich, M. C. Leu, J. L. Lumley, F. K. Moore, R. M. Phelan, S. L. Phoenix, S. B. Pope, E. L. Resler, Jr., S. F. Shen, D. G. Shepherd, D. L. Taylor, K. E. Torrance, K. K. Wang, Z. Warhaft, R. L. Wehe

Members of the faculty of the graduate Fields of Aerospace Engineering and of 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 this basic branch of engineering, as well as an introduction to the many professional and technical areas with which mechanical engineering is particularly concerned. Two main areas of concentration, corresponding to the two major streams of mechanical engineering technology, are offered in the field program.

Mechanical systems and design treats 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, vibrations and control systems, and manufacturing engineering.

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

In addition to the Common Program requirements, the current Field Program in Mechanical Engineering requirements for the Bachelor of Science degree follow. (Requirements listed are those now in effect for the class of 1985 and beyond and are subject to change by the M&AE faculty. Requirements for earlier classes differ somewhat from those listed here.)

	Credits
Engr 202, Mechanics of Solids (also T&AM 202)	3
Engr 203, Dynamics (also T&AM 203)	3
Engr 210, Introduction to Electrical Systems (also Ele E 210)	3
Engr 221, Thermodynamics (also M&AE 221)	3
M&AE 311, Materials and Manufacturing Processes	3
M&AE 323, Introductory Fluid Mechanics	4
M&AE 324, Heat Transfer	3
M&AE 325, Mechanical Design and Analysis	4
M&AE 326, Systems Dynamics	4
M&AE 327, Mechanical Engineering Laboratory	4
Engineering elective	3
Mathematics elective	3
Two field electives	6

Recommended (but not required) for students without previous experience in mechanical drawing are either:

Engr 102, Drawing and Engineering Design (also M&AE 102)	1
or	
Ag En 153, Engineering Drawing	2

The computer applications requirement of the Common Program may be satisfied by several courses including M&AE 489, M&AE 570, and M&AE 575.

The engineering elective is chosen from an approved list of technical courses. The mathematics elective is chosen from an approved list composed of courses from several departments and generally is taken in the upperclass years. The two field electives are selected from an approved list of courses offered by the School of Mechanical and Aerospace Engineering.

Certain courses can be chosen so as to satisfy requirements of both the Common Program and the field program. Specifically, the Mechanics of Solids (Engr 202) requirement of the field program will be waived if the course is used to satisfy the Engineering distribution requirement of the Common Program. Similarly, the Dynamics (Engr 203) requirement of the field program will be waived if the course is used to satisfy either the approved elective or free elective requirement of the Common Program. However, if other field program requirements are used to satisfy Common Program requirements, they must be replaced by alternative technical electives.

If Introduction to Mechanical Properties of Materials (MS&E 261) is taken before entry into the field program, Materials and Manufacturing Processes (M&AE 311) *may* be replaced by an alternate technical elective, although M&AE 311 is still recommended.

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

The undergraduate Field Program in Mechanical Engineering is a coordinated sequence of courses beginning in the second year and extending through the fourth year. Mechanics of Solids (Engr 202) must be taken in the second year, and both Dynamics (Engr 203) and Thermodynamics (Engr 221) should also be taken at that time, since they are prerequisites for courses that generally follow in the third year.

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 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, 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 Master of Engineering (Aerospace) program is designed to increase the student's facility in the application of the basic sciences to important professional problems. 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.

General admission and degree requirements are described in the introductory section under "College of Engineering."

Required courses for the M.Eng. (Aerospace) degree include two related sequences from the following list.

Core Courses Available	*Credits*
M&AE 459, Plasma Energy Systems	3
M&AE 506, Aerospace Propulsion Systems	3
M&AE 507, Dynamics of Flight Vehicles	3
M&AE 530, Fluid Dynamics	3
M&AE 531, Boundary Layers	3
M&AE 543, Combustion Processes	3
M&AE 569, Mechanical and Aerospace Structures I	3
M&AE 570, Mechanical and Aerospace Structures II	4
M&AE 601, Foundations of Fluid Dynamics and Aerodynamics	4
M&AE 602, Incompressible Aerodynamics	4
M&AE 603, Compressible Aerodynamics	4
M&AE 608, Physics of Fluids I	4
M&AE 609, Physics of Fluids II	4
M&AE 610, Gasdynamics	4
M&AE 630, Atmospheric Turbulence and Micrometeorology	4
M&AE 648, Seminar on Combustion	4
M&AE 653, Experimental Methods in Fluid Mechanics and Combustion	4
M&AE 704, Theory of Viscous Flows	4
M&AE 707, Aerodynamic Noise Theory	4
M&AE 733, Stability of Fluid Flow	4
M&AE 734, Turbulence and Turbulent Flow	4
M&AE 737, Numerical Methods in Fluid Flow and Heat Transfer	4

Also required are 6 credits of technical electives. A list of suggested electives is available from the M.Eng. (Aerospace) program representative in Upson Hall. Further requirements include 6 credits of mathematics (T&AM 610–611 or Mathematics 415–416 or the equivalent), participation in the weekly colloquium (1 credit each term), one advanced seminar (2 credits), and one professional design project (2 credits). A total of 30 credits, including the project, are required.

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 finite element and numerical methods. Professional design projects may be arranged in any of these areas.

Master of Engineering (Mechanical) Degree Program

The Master of Engineering (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 bioengineering, machine dynamics and control, mechanical analysis and development, vehicles and propulsion, propulsion engines, energy systems, thermal environment, manufacturing engineering, and materials removal. 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.

The design course (M&AE 590), which may be undertaken individually or by a small team, is a significant part of the program. Although "design" is interpreted broadly, the project should clearly involve the creation and evaluation of alternative solutions to an engineering problem. Some recent projects have been concerned with the design and analysis of crankshaft and crankcase structures, the thermal design of spacecraft components, the design of orthopedic implants, the University's energy policy, energy self-sufficiency, a new type of wind turbine, pollution control in automobile engines, motorcycle suspensions, and the analysis and design of flywheel–internal combustion engine hybrid drives for short-range cars.

A coordinated program of courses for the entire year is agreed upon by the student and the faculty adviser. The proposed curriculum together with a statement of overall objectives and a statement of the purpose of the major is submitted for approval to the Master of Engineering Committee in the School of Mechanical and Aerospace Engineering. 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 21 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 undergraduates if they have not already done so before entering the program. Courses in advanced engineering mathematics or statistics are particularly recommended.

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 K. B. Cady (faculty representative), D. D. Clark, H. H. Fleischmann, D. A. Hammer, and V. O. Kostroun.

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.

College Programs

The suggested curriculum for the College Program in Nuclear Engineering includes NS&E 303, 304, 305, Introduction to Nuclear Science and Engineering I, II, and III, plus two of the four courses A&EP 612, A&EP 651, A&EP 633, and A&EP 609. Also available is the College Program in Energy Conversion, a synthesis of nuclear, thermal, and electrical engineering. See the introductory section under "College of Engineering" for a general description of the College Program.

Master of Engineering (Nuclear) Degree Program

The two-term curriculum leading to the degree of Master of Engineering (Nuclear) 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 612, Nuclear Reactor Theory I
A&EP 633, Nuclear Reactor Engineering
A&EP 609, Low-Energy Physics
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, Transport Processes II
Ele E 581, Introduction to Plasma Physics
Ele E 582, Advanced Plasma Physics
Ele E 571, Feedback Control Systems
Ele E 572, Digital Control Systems
A&EP 613, Nuclear Reactor Theory II
A&EP 652, Advanced Nuclear and Reactor Laboratory
A&EP 636, Seminar on Thermonuclear Fusion Reactors
A&EP 638, Intense Pulsed Electron and Ion Beams: Physics and Technology
NS&E 605, Interaction of Radiation and Matter
Chem E 627, Nuclear Chemical Engineering
MS&E 705, The Effects of Radiation on Materials

Operations Research and Industrial Engineering

G. L. Nemhauser, director; L. E. Trotter, Jr., associate director; L. J. Billera, graduate faculty representative; J. A. Muckstadt, M.Eng. faculty representative; R. E. Bechhofer, R. G. Bland, D. C. Heath, P. L. Jackson, W. F. Lucas, W. L. Maxwell, N. U. Prabhu, T. J. Santner, L. W. Schruben, M. S. Taqqu, H. M. Taylor 3d, M. J. Todd, B. W. Turnbull, L. I. Weiss

Bachelor of Science Curriculum

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 an introduction to the technical and professional areas with which operations researchers and industrial engineers are concerned.

A student who plans to enter the Field Program in Operations Research and Industrial Engineering should take Introductory Engineering Probability (Engr 260). For a student who has not taken Engr 260, entry into the field program in OR&IE is possible only by permission of the associate director. In addition, the following courses are recommended: Introduction to Electrical Systems (Ele E 210 or Engr 210); Mechanics of Solids (T&AM 202 or Engr 202); and Computers and Programming (Com S 211 or Engr 211). Early consultation with an OR&IE faculty member or with the associate director can be helpful in making appropriate choices. In the junior year the following courses are required:

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
Com S 211, Computers and Programming*	3
Liberal studies elective	3
Term 6	
OR&IE 321, Optimization II	4
OR&IE 361, Introductory Engineering Stochastic Processes	4
Technical elective	3
Behavioral science†	3
Liberal studies elective	3

*If Com S 211 is completed during the sophomore year, an appropriate 3-credit technical elective must be substituted.

†The behavioral science requirement can be satisfied by any one of several courses of an advanced nature, including Business and Public Administration NCE 540 (recommended for those contemplating the pursuit of a graduate business degree), B&PA NCE 541; Hotel Administration 211; I&LR 120, 121, 150, 151, 260, and 320. The adviser must approve the selection in all cases.

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

	Minimum credits
OR&IE 580, Digital Systems Simulation	4
Four courses consisting of sequences as described below	12
Technical elective	3
Two liberal-studies electives	6
Two free electives	6

Available OR&IE sequences are as follows:

Industrial systems: two or four courses selected from OR&IE 410; 417, 421, and 562*, and B&PA NBA 562
Optimization methods: OR&IE 431 and 435
Applied probability and statistics: two or four courses selected from OR&IE 462, 471, 472, 561, 563, and 570

*OR&IE 410 and 421 must be selected by students who plan to participate in the cooperative program with the Graduate School of Business and Public Administration.

Students who want to apply OR&IE methodology in other technological areas may substitute one course sequence appropriate to the outside discipline for one of the required OR&IE sequences. Examples of possible sequences outside OR&IE can be obtained from the school office and must be approved by the adviser.

These options, together with an appropriate choice of technical electives, enable a student to earn at least 12 credits in a technological field other than OR&IE. Through an appropriate choice of free electives also, as many as 18 credits can be earned in the secondary discipline.

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 Master of Engineering (OR&IE) program is integrated with the undergraduate Field Program in Operations Research and Industrial Engineering. Also welcome are requests for admission from Cornell undergraduates in engineering programs other than OR&IE, 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.

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

Fall term	*Credits*
OR&IE 516, Mathematical Models—Development and Application	4
OR&IE 580, Digital Systems Simulation	4
OR&IE 893, Applied OR&IE Colloquium	1
OR&IE 599, Project	1
Two technical electives	6
Spring term	
OR&IE 551, Advanced Engineering Economic Analysis	4
OR&IE 894, Applied OR&IE Colloquium	1
OR&IE 599, Project	minimum of 4
Two technical electives	6
Spring term	
OR&IE 551, Advanced Engineering Economic Analysis	4
OR&IE 894, Applied OR&IE Colloquium	1
OR&IE 599, Project	minimum of 4
Two technical electives	6

The electives specified above will normally be chosen from graduate courses offered by the School of Operations Research and Industrial Engineering.

II. For matriculants from other fields who minimally fulfill the prerequisite requirements. Students who have the equivalent of OR&IE 370, 622, and 623 will take technical electives in their place.

Fall term	*Credits*
OR&IE 370, Introduction to Statistical Theory with Engineering Applications	4
OR&IE 622, Operations Research I	3
OR&IE 516, Mathematical Models—Development and Application	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 623, Operations Research II	3
OR&IE 551, Advanced Engineering Economic Analysis	4
OR&IE 894, Applied OR&IE Colloquium	1
OR&IE 599, Project	minimum of 4
Technical elective	3

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 various operating organizations such as manufacturing firms, retailing organizations, service organizations, government agencies, and educational institutions.

Cooperative Program with Business and Public Administration

Undergraduates majoring in operations research and industrial engineering may be interested in a cooperative program at Cornell that leads to both Master of Engineering and Master of Business

Administration (M.B.A.) degrees. With appropriate curriculum planning, such a combined B.S.–M.Eng.–M.B.A. program can be completed in six years.

An advantage for OR&IE majors is that they study, as part of their undergraduate curriculum, several subjects that are required for the Master of Business Administration 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 the systems.) Getting started early on meeting the business-degree requirements permits students accepted into the cooperative program to earn both the Master of Engineering (OR&IE) and Master of Business Administration degrees in two years rather than the three years such a program would normally take.

Essential aspects of the program as it pertains to the M.B.A. degree are:

1) By the end of the fifth year, the candidate completes—through course work, advanced standing, or exemption examinations—the core course work required for the M.B.A. degree, except for B&PA NBP 503, Business Policy.
2) A maximum of 30 credits toward the M.B.A. degree can be earned for courses taken before the start of the sixth year; these credits may be earned in the undergraduate B.S. program, in the M.Eng. program, or in the School of Business and Public Administration.
3) During the sixth year, over a period of two semesters, the candidate earns 26 credits in elective courses approved by the business school, plus 4 credits for B&PA NBP 503, Business Policy.

In accordance with this plan, the candidate would qualify for the Bachelor of Science degree at the end of four years, the Master of Engineering (OR&IE) degree at the end of five years, and the Master of Business Administration 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.

Theoretical and Applied Mechanics

F. C. Moon, chairman; J. A. Burns, H. D. Conway, E. W. Hart, P. J. Holmes, C. Y. Hui, J. T. Jenkins, R. H. Lance, G. S. S. Ludford, S. Mukherjee, Y. H. Pao, R. H. Rand, A. L. Ruina, W. H. Sachse

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 underclass engineering curriculum in the Division of Basic Studies.

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.

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	Ag En
Applied and Engineering Physics	A&EP
Chemical Engineering	Chem E
Civil and Environmental Engineering	CEE
Computer Science	Com S
Electrical Engineering	Ele E
Geological Sciences	Geol
Materials Science and Engineering	MS&E
Mechanical and Aerospace Engineering	M&AE
Nuclear Science and Engineering	NS&E
Operations Research and Industrial Engineering	OR&IE
Theoretical and Applied Mechanics	T&AM

Engineering Common Courses

102 Drawing and Engineering Design (also M&AE 102) Fall, spring. 1 credit. Half-term course offered twice each semester. Recommended for students without previous mechanical drawing experience. S-U grades optional.
2 lecs, 1 lab.
Practical demonstration of the relationship between engineering principles and the creative solution of real problems. Drawing and graphic techniques useful in design, analysis, and presentation of ideas. Computer graphics applied to problems of engineering design through use of CADIF (Computer-Aided Design Instructional Facility).

105 Introduction to Computer Programming Fall or spring. 4 credits. The course content is the same as that of Computer Science 100.
2 lecs, 1 rec (optional), 3 evening exams, final exam.
An introduction to elementary computer programming concepts. Emphasis is on techniques of problem analysis and algorithm and program development. The subject of the course is programming, not a particular programming language. The principal programming language used is PL/I; FORTRAN is introduced and used for final problems. 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.

202 Mechanics of Solids Fall or 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, singularity functions; plane stress; Mohr's circle; bending and torsion of bars; buckling and plastic behavior.

203 Dynamics Fall or 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, and a rigid body. Kinematics, motion relative to a moving frame. Impulse, momentum, angular momentum, energy. Rigid-body kinematics, angular velocity, moment of momentum and the inertia tensor. Euler equations, the gyroscope.

210 Introduction to Electrical Systems Fall or spring. 3 credits. Prerequisites: Mathematics 192 and Physics 112.
3 lec-rec.
Circuit elements and laws, natural response of linear systems; impedance and pole-zero concepts; complex frequency and phasors; forced response and power systems; transfer function and frequency response; low-frequency terminal characteristics of diodes and transistors; linear models of electronic devices; bias circuits and frequency response of amplifiers; operational amplifiers, feedback, and oscillators.

211 Computers and Programming (also Com S 211) Fall or spring. 3 credits. Prerequisite: Computer Science 100 or Engr 105 or equivalent programming experience.
2 lecs, 1 rec.
Intermediate programming in a high-level language and introduction to computer science. Topics include program development, invariant relations, block structure, recursion, parallel processing, data structures, analysis of algorithms, and a brief introduction to machine architecture and machine-level programming. PL/I is the principal programming language used.

219 or 220 Mass and Energy Balances 219, fall; 220, summer. 3 credits. Prerequisites: one year of freshman chemistry. 219 is recommended for students planning to enter the Field Program in Chemical Engineering.
R. G. Thorpe.
Engineering problems involving material and energy balances. Batch and continuous reactive systems in the steady and unsteady states. Humidification processes. Chemical Engineering 220 differs from 219 in that is 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, two preliminary examinations, and a final examination; superior students may earn exemption from the final examination.

221 Thermodynamics Fall or spring. 3 credits. Prerequisites: Mathematics 191–192 and Physics 112.
3 recs.
The definitions, concepts, and laws of thermodynamics. Applications to ideal and real gases, multiphase pure substances, gaseous mixtures, and gaseous reactions. Heat-engine and heat-pump cycles. An introduction to statistical thermodynamics.

260 Introductory Engineering Probability Fall or spring. 3 credits. Prerequisite: first-year calculus.
3 lecs.
The basic tools of probability and their use in engineering. 260 may be the last course in probability for some students, or it may be followed by OR&IE 361, Stochastic Processes I, or by OR&IE 370, Statistics. 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 or 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, oxide layers and metal films that are used in modern integrated circuits. Crystal structure, growth of semiconductors, deposition of thin films, electrical conduction, p-n junctions, transistors, and light-emitting diodes. Interplay between structural and electrical properties and their application to the design of semiconductor devices and integrated circuits.

270 Basic Engineering Probability and Statistics Fall or spring. 3 credits. Students who intend to enter the upperclass Field Program in Operations Research and Industrial Engineering should take OR&IE 260 instead of this course. Prerequisite: first-year calculus.
3 lecs.
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.

321 Numerical Methods (also Com S 321) Fall or spring. 4 credits. Prerequisites: Mathematics 293 or 221 and knowledge of FORTRAN equivalent to what is taught in Com S 100.
3 lecs.
Students solve representative problems by programming appropriate algorithms and using library programs. Numerical methods for systems of linear equations, interpolation, integration, ordinary differential equations, nonlinear equations, optimization, and linear least squares.

Applied and Engineering Physics

110 The Laser and Its Applications in Science, Technology, and Medicine Fall, spring. 3 credits. This is a course in the "Introduction to Engineering" series.
2 lecs, 1 lab. T. A. Cool and A. Lewis.
The principles of laser action, types of laser systems, and the applications of lasers in science, technology, and medicine are discussed. In the laboratory the student builds and operates 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 the student to current fields of laser application and research.

206 Introduction to Biophysics Fall. 3 credits. Prerequisite: concurrent registration in Physics 213 or permission of instructor.
3 lecs. A. Lewis.
The use of quantitative principles to elucidate biological systems. Intended for students of the physical sciences and engineers who want to see how biological systems exemplify the ultimate in design. Topics, chosen to show the interdependence of all living matter, are photosynthetic energy conversion, the products of photosynthetic energy conversion, 0_2 and starch (focusing on hemoglobin and metabolism/membranes), and perception and replications.

217 The Physics of Energy Spring. 3 credits. Prerequisite: Physics 213.
2 lecs, 1 rec-lab. T. N. Rhodin.
The basic physical principles and the fundamental engineering problems associated with present and potential approaches to large-scale energy conversion. In particular, the basic principles and fundamental limitations of the use of nuclear energy (both fission and fusion) and solar energy are presented. One objective of the course is to give a current view of the present status and future directions of research and development in energy-related phenomena.

303 Introduction to Nuclear Science and Engineering I (also NS&E 303) Fall. 3 credits. Prerequisite: Physics 214 or Mathematics 294. This course and A&EP 304 form a coordinated, two-term sequence 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. The sequence can also serve as a basic course for those who do not intend to continue in the field. 303 is a reasonably self-contained unit that can be taken by itself by those desiring only one term.
3 lecs. D. A. Hammer.
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.

304 Introduction to Nuclear Science and Engineering II (also NS&E 304) Spring. 3 credits. Prerequisite: A&EP 303.
3 lecs. D. D. Clark.
Introduction to aspects of nuclear reactor engineering and to controlled fusion. Topics include heat-transfer and safety problems in fission reactors; principles, configurations, and engineering problems of proposed fusion reactors; radiation detection, shielding, biological effects of radiation, and materials damage.

333 Mechanics of Particles and Solid Bodies Fall. 4 credits.
3 lecs, 1 rec. J. Silcox.
Newton's laws; coordinate transformations; generalized coordinates and momenta. Lagrangian and Hamiltonian formulation; applications to oscillator, restrained motion, central forces, small vibrations of multiparticle systems, motion of rigid body.

355 Intermediate Electromagnetism Fall. 4 credits. Prerequisites: Physics 214 and coregistration in Mathematics 421 or T&AM 610, or permission of instructor.
3 lecs, 1 rec. B. Kusse.
Topics: vector calculus; electrostatics, magnetostatics, and introduction phenomena; Laplace's equation solutions in Cartesian, cylindrical, and spherical systems; dielectrics, paramagnetic and diamagnetic materials, electric and magnetic forces, energy storage, skin effect, quasistatics. Emphasis on physical concepts and applications.

356 Intermediate Electrodynamics Spring. 4 credits. Prerequisites: A&EP 355, coregistration in Mathematics 422 or T&AM 611, or permission of instructor.
3 lecs, 1 rec. M. Nelkin.
Development of electromagnetic wave phenomena and radiation. Topics include transmission lines, waveguides, wave properties of dispersive media, radiation and scattering phenomena, reciprocity, physical optics, and special relativity.

361 Introductory Quantum Mechanics Spring. 4 credits. Prerequisites: A&EP 333 or Physics 318; coregistration in Mathematics 422 or T&AM 611 and in A&EP 356 or Physics 326.
3 lecs, 1 rec. V. O. Kostroun.
A first course in the systematic theory of quantum phenomena. Topics include the square well, harmonic oscillator, hydrogen atom, and perturbation theory. At the level of Chapters 4–9 of *Modern Physics and Quantum Mechanics* by Anderson.

363 Electronic Circuits (also Physics 360) Fall or spring. 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 sec, 2 labs. Spring: A. Kuckes.
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 build digital circuits that incorporate Schmidt triggers, comparators, combinatorial and sequential logic using medium-scale integrated circuits. The above circuits are also interfaced to a microprocessor whose architecture, machine instruction set, and programming principles are studied. At level of *Principles of Electronic Instrumentation* by Diefenderfer.

[**401 Physics of Atomic and Molecular Processes** Fall. 3 credits. Prerequisite: A&EP 361, Physics 443, or permission of instructor. Not offered 1982–83.
An introduction to the basics of contemporary problems in the physics of atomic and molecular processes, including atomic structure, chemical bonding, polarization, radiation resonance processes, and atomic and molecular spectroscopy.]

423 Statistical Thermodynamics Spring. 4 credits. For engineering physics seniors; others by permission of instructor.
3 lecs, 1 rec. B. R. Kusse.
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 and Thermal Physics* by Reif.

434 Continuum Physics Fall. 4 credits. Prerequisite: A&EP 333 and 356 or equivalent.
3 lecs, 1 rec. M. Nelkin.
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, Bernoulli'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.

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.

601 Photosynthesis (also Biological Sciences 445) Fall. 3 credits. Prerequisites: Chemistry 104 or 208, Mathematics 106 or 111, and Physics 102 or 208, or permission of instructor. Offered alternate years.
R. K. Clayton.
A detailed study of the process by which plants use light in order to grow, emphasizing physical and physiochemical aspects.

606 Introduction to Plasma Physics (also Electrical Engineering 581) Fall. 3 credits. Prerequisites: A&EP 355, 356, or equivalent. Open to fourth-year students at discretion of instructor.
3 lecs. R. N. Sudan.

Plasma state; motion of charged particles in fields; collisions, coulomb scattering; transport coefficients, ambipolar diffusion, plasma oscillations and waves; bydromagnetic equations; hydromagnetic stability and microscopic instabilities; test particle in a plasma; elementary applications.

607 Advanced Plasma Physics (also Ele E 582)
Spring. 3 credits. Prerequisite: A&EP 606.
3 lecs. R. N. Sudan.
Boltzmann and Vlasov equations; waves in hot plasmas; Landau damping, mocro-instabilities; 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. Not offered 1982–83.
R. V. Lovelace.
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. V. Kostroun.
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.

611 Vision (also Biological Sciences 395) Fall. 3 credits. Prerequisites: Chemistry 104 or 208, Mathematics 106 or 111, Physics 102 or 208, or permission of instructor. Offered alternate years.
R. K. Clayton.
Study of the mechanisms of seeing, embracing biological, physical, and chemical approaches to the subject.

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

613 Nuclear Reactor Theory II Spring. 3 credits. A continuation of A&EP 612, primarily intended for students planning research in nuclear reactor physics and engineering. Prerequisite: A&EP 612.
3 lecs. K. B. Cady.
The Boltzmann linear transport equation, its adjoint, and their approximate solutions are developed and applied to the heterogeneous neutron chain reactor.

[614 Special Topics in Biophysics Offered alternate years. Not offered 1982–83.
W. W. Webb.
Topics, credits, and schedule to be announced. Seminars on selected topics of current interest in biophysics research.]

615 Membrane Biophysics Fall. 3 credits.
W. W. Webb.
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. 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.

[616 Modern Physical Methods in Macromolecular Structure Determination (parallels Physics 464)
Spring. 3 credits. Prerequisite: permission of instructor or a course in quantum mechanics. Intended for advanced undergraduates and graduate students. Offered alternate years. Not offered 1982–83.
A. Lewis.
Modern physical methods of macromolecular characterization, with emphasis on techniques such as subpicosecond and picosecond fluorescence and absorption spectroscopy, excited and ground-state dipole-moment measurement, tunable laser thermal lens spectroscopy, tunable laser Raman and coherent anti-Stokes Raman spectroscopy of ground and excited molecular states, and the measurement of vibrational optical activity. The course should appeal to students who are interested either in the use of such physical techniques for characterizing materials or in the physics of macromolecules and macromolecular assemblies. Macromolecular systems used as examples are of biological interest or are physically interesting polymeric materials.]

[622 Electron Optics Spring. 3 credits. Offered alternate years. Not offered 1982–83.
M. S. Isaacson.
Basic electron optics with emphasis on the fundamental principles of the production and focusing of charged-particle beams. Special consideration is given to the optics appropriate for beam transport and probe forming systems and systems useful in materials characterization. Included are discussions of the calculation of trajectories in multicomponent optical systems, comprehensive treatments of optical aberrations, and practical considerations of electron optical design.]

633 Nuclear Engineering Fall. 4 credits. Prerequisite: introductory course in nuclear engineering.
K. B. Cady.
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.
K. B. Cady.
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. Not offered 1982–83.
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: Ele E 581, 582 (A&EP 606; 607), or equivalent; or permission of instructor.
D. A. Hammer.
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: some nuclear physics.
Two 2½-hour afternoon periods plus 1 lec. Staff.
Lectures on interaction of radiation with matter, radiation biology, and nuclear instruments and measurements. Fifteen experiments are available (from which eight are selected) on nuclear physics, radiation instrumentation and measurements, activation analysis, neutron moderation, and reactor physics and engineering; the subcritical reactor assembly and TRIGA reactor are used. At the level of *Nuclear Radiation Detection* by Price and *Radiation Detection and Measurement* by Knoll.

652 Advanced Nuclear and Reactor Laboratory
Spring. 3 credits. Prerequisites: A&EP 651 and 609 or 612. Offered on independent study basis or, with sufficient demand, as a formal course.
Two 2½-hour afternoon periods.
Laboratory experiments and experimental methods in nuclear physics and reactor physics. Ten experiments are available, some using the Zero Power Reactor critical facility.

653 Special Topics Seminar in Applied Physics
Fall or spring. 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 areas of atomic, plasma, biological, and solid-state physics, as suggested by the students and coordinated by the instructor.

661 Microcharacterization Fall. 3 credits. Prerequisites: Physics 112, 213, and 214, or an introductory course in modern physics.
M. Isaacson.
The basic physical principles underlying the many modern microanalytical techniques available for characterizing materials. Discussion centers on the physics of the interaction process by which the characterization is performed, the advantages and limitations of each technique, and the instrumentation involved in each characterization method (including the charged-particle optics when appropriate).

662 Microprocessing of Materials Spring. 3 credits.
R. A. Buhrman.
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 material 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.
B. W. Batterman.
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.
Informal study under the direction of a member of the University staff. Students are offered some research experience through work on a special problem related to their field of interest.

761 Kinetic Theory (also Ele E 681) Fall. 3 credits. Prerequisites: Ele E 407 or Physics 561 or permission of instructor. Offered alternate years.
2 lecs. R. L. Liboff.
See Electrical Engineering 681 for course description.

762 Physics of Solid Surfaces and Interfaces Spring. 3 credits. Lecture course primarily for graduate and qualified senior students. Prerequisites: Physics 454 and A&EP 361. Similar to MS&E 703. Offered alternate years.
T. N. Rhodin.
A critical presentation of current understanding of the physics and chemistry of surface and interface phenomena in metals, semiconductors, and ionic solids. Application of quantum and statistical mechanics to a discussion of the microscopic behavior of electrons, atoms, ions, and molecules at phase boundaries in condensed matter. Emphasis on the electron structure, surface crystallography, and chemical reactivity of both ideal and practical solid surfaces. Theory and application of modern methods of electron spectroscopy in ultrahigh physics. Material drawn from the current research literature is presented at the level of *The Nature of the Surface Chemical Bond*, edited by Rhodin and Ertl.

Chemical Engineering

101 Nonresident Lectures Fall. Noncredit.
1 lec.
Given by lecturers invited from industry and from selected departments of the University to assist students in their transition from college to industrial life.

219 Mass and Energy Balances (also Engr 219) Fall. 3 credits. Prerequisite: one year of freshman chemistry or permission of instructor.
3 lecs, 1 computing session. R. G. Thorpe.
See description under Engineering Basic Studies.

220 Mass and Energy Balances (also Engr 220) Summer. Not offered during the academic year; available during summer. 3 credits. Prerequisite: one year of freshman chemistry. Chemical Engineering 220 is intended for students who cannot take Chemical Engineering 219.
R. G. Thorpe.
Self-paced audiovisual instruction in the material of Chemical Engineering 219. See description under Engineering Basic Studies.

311 Chemical Engineering Thermodynamics I Fall. 3 credits.
3 lecs, 1 computing session. W. B. Streett.
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.

312 Chemical Engineering Thermodynamics II Spring. 3 credits.
3 lecs, 1 computing session. K. E. Gubbins.
Thermodynamics of mixtures; phase equilibria and phase diagrams. Estimation methods. Heat effects, chemical equilibria.

410 Reaction Kinetics and Reactor Design Fall. 3 credits. Prerequisites: Chem E 312 and 430.
3 lecs. J. F. Cocchetto.
A study of chemical reaction kinetics and principles of reactor design for chemical processes.

421 Industrial Organic Chemical Processes Spring. 2 credits. Prerequisite: Chemistry 253 or 357.
2 lecs. F. Rodriguez.
Study of commercial manufacturing processes for important organic chemicals.

430 Introduction to Rate Processes Fall. 3 credits. Prerequisites: Chem E 219 and engineering mathematics sequence.
3 lecs, 1 computing session. C. Cohen.
Fundamentals of fluid mechanics and heat transfer; solutions to problems involving viscous flow, heat conduction and convection, friction factors and heat transfer coefficients, macroscopic balances, elementary applications.

431 Analysis of Separation Processes Spring. 3 credits. Prerequisites: Chem E 430 and familiarity with FORTRAN or PL/I.
3 lecs, 1 computing session. R. G. Thorpe.
Analysis of separation processes involving phase equilibria and rate of mass transfer; some use of the digital computer. Phase equilibria; binary, multicomponent, and extractive distillation; liquid-liquid extraction; gas absorption; crystallization.

432 Chemical Engineering Laboratory Fall. 3 credits. Prerequisites: Chem E 430, 431.
2 lecs, 1 lab. F. Vorhis and staff.
Laboratory experiments in fluid dynamics, heat and mass transfer, other operations. Correlation and interpretation of data. Technical report writing.

433 Project Laboratory Fall or spring. Credit variable. Prerequisite: Chem E 432.
Special laboratory projects involving bench-scale or pilot-plant equipment.

434 Transport Phenomena Spring. 3 credits. Strongly recommended for those interested in graduate study in chemical engineering.
3 lecs. W. L. Olbricht.
An introduction to momentum, heat, and mass transport. Development of governing equations. Solutions of problems involving laminar flow of purely viscous liquids, heat transfer, and convective diffusion.

461 Chemical Process Evaluation Fall. 3 credits.
P. Harriott.
Study of some important chemical processes, covering raw material sources, analysis of reaction conditions, and product purification.

462 Chemical Process Synthesis Spring. 4 credits. Prerequisite: Chem E 432.
R. L. Von Berg and staff.
A consideration of process and economic alternatives in selected chemical processes; design and assessment.

463 Computer Applications in Chemical Engineering Spring. 3 credits. Prerequisite: Com S 100 or equivalent.
2 lecs, 1 computing session. P. Clancy.
Modern computing techniques for solving current problems in chemical engineering. Basic research and applications both in industry and in the university. Computer graphics, on-line data analysis, and numerical manipulation. Extensive hands-on opportunities.

563 Process Equipment Design and Selection Fall. 3 credits. Prerequisite: Chem E 430 and 431 or equivalent.
3 lecs. J. C. Smith.
Performance, selection, and design of process equipment; storing, transporting, mixing, heating, and separating fluids and solids. Process development and decision among alternates.

564 Design of Chemical Reactors and Multiphase Contacting Systems Spring. 3 credits.
3 lecs. P. Harriott.
Design, scale-up, and optimization of chemical reactors with allowance for heat and mass transfer, nonideal flow, and catalyst aging. Selection of systems for gas-liquid contacting, including stirred tanks, fluidized beds, and fixed beds.

565 Design Project Spring. 3 or 6 credits. Prerequisites: Chem E 563, 564.
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: concurrent registration in 462 or a previous course in process design.
3 lecs. G. F. Scheele.
An introduction to the synthesis and use of computer systems for steady-state simulation and optimization of chemical processes.

595, 596 Special Projects in Chemical Engineering Fall or spring. Credit variable. Research or studies on special problems in chemical engineering.

611 Phase Equilibria Fall. 3 credits. Prerequisite: physical chemistry.
3 lecs. R. G. Thorpe.
A detailed study of the pressure-temperature-composition relations in binary and multicomponent heterogeneous systems where several phases are of variable composition. Prediction of phase data.

621 Petroleum Refining Spring. 3 credits. Prerequisite: Chem E 461.
3 lecs. H. F. Wiegandt.
A study of processes used to refine petroleum. Recent process developments, including those for selected petrochemicals.

623 Synthetic Fuels Spring. 3 credits.
P. Harriott.
Energy resources and projected consumption. Gasification and liquefaction of coal and oil shale. Synthesis of methane, methanol, and hydrogen. Efficiency and economics of fuel production and use.

[**627 Nuclear Chemical Engineering** Fall. 2 credits. Prerequisite: permission of instructor. Not offered 1982–83.
2 lecs. R. L. Von Berg.
Uranium refining, isotope separation, fuel manufacture, spent-fuel processing, radioactive waste disposal, radiation damage, radiation chemistry.]

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

[**641 Physical Polymer Science** Fall. 3 credits. Prerequisite: Chem E 640 or equivalent. Offered alternate years; not offered 1982–83.
3 lecs. C. Cohen.
Thermodynamic and flow properties of polymer solutions. Phase separation in mixtures. Principal characterization techniques. Viscoelastic and transport properties of bulk polymers. Models of the glass transition. Applications to selected polymer processes.]

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.

644 Microbial Engineering Spring. 3 credits. Prerequisites or corequisites: Chemistry 288 and any course in microbiology.
2 lecs, rec. M. L. Shuler.
An advanced discussion of fermentation as a unit process. Topics include sterilization, aeration, agitation, and continuous fermentation.

647 Wastewater Engineering in the Process Industries Fall. 3 credits. Prerequisites: organic and physical chemistry; Chem E 430 or equivalent.
M. L. Shuler.
Introduction to general and legal problems of pollution control, including some descriptive technology. Major emphasis, however, is on the quantitative engineering aspects of design and operation. Both biological and physical chemical methods as they apply to the treatment of strong and special wastes from the chemical and allied industries are discussed.

648 Polymer Processes Spring. 3 credits. Prerequisite: 640 or permission of instructor.
3 lecs. F. Rodriguez.
Production and applications of polymers. Discussion of stabilization and degradation, including processes for recycling and disposal of plastics and related products.

651 Numerical Methods in Chemical Engineering Fall. 3 credits.
3 lecs. G. F. Scheele.
Solution of single and sets of algebraic equations, polynomial approximations, integration, initial and boundary-value ordinary differential equations, partial differential equations, statistical design of experiments.

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

671 Process Control Spring. 3 credits. Prerequisites: Chem E 410 and 430.
3 lecs. J. F. Cocchetto.
Analysis of process dynamics and design of control systems that will maintain output specifications in spite of input disturbances.

672 Process Control Laboratory Spring. 1 credit. Prerequisite: concurrent registration in Chem E 671.
1 lab. J. F. Cocchetto.
Experiments on controller calibration, dynamics of first- and second-order systems, and dynamics and control of actual or simulated process systems.

673 Applied Surface Chemistry and Physics Spring. 2 credits.
R. P. Merrill.
Topics in the chemistry and physics of solid surfaces and their applications to practical problems. In 1983 the course will concentrate on the physics and chemistry of catalytic systems from a fundamental viewpoint. Discussion of several practical catalytic systems will be included.

692, 693, 694 Research Project Fall or spring. 3 credits; additional credit by special permission. Prerequisite: Chem E 430.
Research on an original problem in chemical engineering.

711 Advanced Chemical Engineering Thermodynamics Fall. 3 credits. Prerequisite: Chem E 312 or equivalent.
3 lecs. K. E. Gubbins.
Application of general thermodynamic methods to advanced problems in chemical engineering. Evaluation, estimation, and correlation of properties; chemical and phase equilibrium.

713 Applied Chemical Kinetics Fall. 3 credits. Prerequisite: physical chemistry.
R. P. Merrill.
Fundamentals of the kinetics of reacting systems. Collision theory, unimolecular rate theory, transition-state theory, and the use of simple statistical models to represent reacting chemical systems are stressed. The application of these concepts to nonideal environments, solvent effects, and reactions on solids is presented with some emphasis on catalytic phenomena.

731 Advanced Transport Phenomena Spring. 3 credits. Prerequisite: Chem E 434 or equivalent.
3 lecs. C. Cohen.
Viscous laminar flow of Newtonian and Power-Law fluids. Solutions of the Navier-Stokes equations for selected steady- and unsteady-state problems. An integrated presentation of momentum, mass, and heat transfer. Models of mass and heat transfer.

751 Mathematical Methods of Chemical Engineering Analysis Spring. 4 credits.
4 lecs. P. H. Steen.
Application of advanced mathematical and numerical techniques to chemical engineering analysis. Linear and nonlinear ordinary differential equations, partial differential equations, vector and tensor analysis.

772 Theory of Molecular Liquids Spring. 3 credits. Prerequisite: Chem E 711 or equivalent.
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.

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

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

891, 892, 893 Thesis Research Fall or spring. Thesis research for the M.S. degree in chemical engineering.

991, 992, 993, 994, 995 Thesis Research Fall or spring.
Thesis research for the Ph.D. degree in chemical engineering.

Civil and Environmental Engineering

The numbering of courses in the School of Civil and Environmental Engineering has been changed. The middle digits of course numbers now designate specific areas of study: 1, Environmental Sensing, Measurement, and Evaluation; 2, Public and Environmental Systems Engineering; 3, Fluid Mechanics and Hydrology; 4, Geotechnical Engineering; 5, Environmental Quality Engineering; 6, Transportation Engineering; 7 and 8, Structural Engineering; 9, Water Resources Planning and Analysis; and 0, Professional Practice.

Current and Former Course Numbers

Old No.	New No.	Old No.	New No.
A321	310	A691	616
A680	610	A692	617
A683	611	A694	618
A685	612	A696	619
A687	613	A801	810
A688	614		
B301	321	B416	426
B302	322	B614	624
B303	323	B615	625
B305	325	B616	626

Old No.	New No.	Old No.	New No.
B617	628	B792	722
B693	629	B794	729
B791	721		
C301	331	C641	636
C302	332	C642	731
C609	430	C643	732
C615	630	C651	733
C618	631	C691	637
C620	632	C693	638
C621	633	C694	639
C622	634	C744	734
C631	635	C792	735
C633	730		
D301	341	D711	741
D606	640	D712	742
D607	641	D714	744
D631	642	D715	745
D632	643	D717	746
D691	647	D718	747
D693	648	D719	748
D694	649	D792	749
D710	740		
E301	351	E712	752
E604	652	E715	755
E610	653	E716	756
E611	654	E791	757
E631	655	E792	758
E633	656	E794	759
E638	658	E801	851
E693	659		
F301	361	F645	669
F621	660	F646	666
F623	661	F791	761
F624	663	F792	762
F625	664	F793	763
F643	668	F794	764
G301	371	G713	772
G302	372	G715	773
G303	373	G716	774
G304	374	G717	775
G305	375	G718	776
G351	376	G719	777
G608	670	G720	778
G610	672	G722	779
G612	673	G732	780
G614	674	G733	781
G652	675	G734	782
G653	676	G757	783
G654	678	G791	784
G655	679	G792	785
G693	680	G794	786
G709	770	G801	880
G711	771		
H615	691	H628	694
H624	692	H629	695
H626	693		
K301	301	K511	502
K370	304	K521	503
K510	501	K601	601

301 Numerical Solutions to Civil Engineering Problems Fall. 3 credits.
Introduction to numerical and computer methods through consideration of typical problems drawn from a number of disciplines within civil and environmental engineering. Topics include computer use, computer programming, data handling, numerical analysis, and the role of computing in the civil engineering profession.

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 some nonparametric statistics and decision theory. 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.

310 Surveying for CEE Facilities Fall, spring (on demand). 3 credits. Prerequisites: Physics 112, Math 192. Recommended: Engr 260 or 270.
2 lecs, 1 lab, Evening tests. G. B. Lyon.
This course specifically focuses on surveying and use of results from surveying operations for planning, design, and construction of civil engineering facilities. Topics include measurements and data reduction for determination of position, and changes therein, of terrestrial features; development and use of criteria for quality control; highway curves; earthwork quantities and distribution analysis for minimum construction cost; terrestrial and photogrammetric compilation of topographic maps; use of topographic maps in planning and design; and selected topics in the construction of civil and environmental engineering facilities.

321 Microeconomic Analysis (also Economics 311) Fall. 4 credits. Prerequisite: one year of college-level mathematics. A liberal elective for engineers.
L. M. Falkson.
Intermediate microeconomic analysis similar to Economics 311 but emphasizing mathematical techniques. Theory of households, firms, monopoly and competitive markets, distribution and equilibrium welfare economics.

322 Economic Analysis of Government (also Economics 308) Spring. 4 credits. Prerequisites: one year of college-level mathematics, plus CEE 321 or Economics 311.
R. E. Schuler.
Analysis of government intervention in a market economy. Public goods, public finance, cost-benefit analysis, environmental regulation, and macroeconomic topics.

323 Engineering Economics and Management Spring. 3 credits. Aimed at juniors and seniors; not intended for students with substantial background in business economics or methods of operations research.
J. R. Stedinger.
Intended to give the student a working familiarity with the principles for making economic comparisons and for reaching decisions about alternative engineering projects. Project management, inflation, taxation, financial planning and basic operations-research techniques are discussed.

325 Social Implications of Technology Fall. 3 credits. Approved liberal elective. Not open to freshmen.
W. R. Lynn.
Examines selected issues pertaining to the development, implementation, and assessment of technology. Special emphasis is given to social, political, and economic aspects of current problems that have important technological components.

331 Fluid Mechanics Fall. 4 credits. Prerequisite: Engr 203 (may be taken concurrently).
3 lecs, 1 rec. Evening exams. Staff.
Hydrostatics, the basic equations of fluid flow, potential flow and dynamic pressure forces, viscous flow and shear forces, steady pipe flow, turbulence, dimensional analysis, selection of turbomachinery.

332 Hydraulic Engineering Spring. 3 credits Prerequisite: CEE 331.
2 rec, 1 lab, field trips. Staff.
Steady open-channel flow, river modeling, unsteady pipe flow, theory of turbomachinery. Laboratory includes number of experiments in hydraulic and river engineering.

341 Introductory Soil Mechanics Spring. 3 credits.
2 lecs, 1 lab-tutorial. T. D. O'Rourke.
Soil as an engineering material. Chemical and physical nature of soil. Engineering properties of soil. Stresses and stress analysis in soil. Introduction to stability, earth pressure, and other design problems. Introduction to laboratory testing.

351 Environmental Quality Engineering Spring. 3 credits.
J. M. Gossett.
Introduction to engineering aspects of environmental quality control. 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.
R. I. Dick.
Analysis of contemporary threats to human health in public water supply systems. Potable water quality criteria and standards. Water quality control theory. Design of facilities for obtaining, treating, storing, and distributing water.

361 Introduction to Transportation Engineering Spring. 3 credits.
M. A. Turnquist.
Introduction to technological, economic, and social aspects of transportation. Emphasis on the form and functioning of transportation systems and their components. Vehicle and system technology, traffic flow and control, terminal operations, supply-demand interactions, system planning and management, and institutional issues.

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

372 Structural Engineering II Spring. 4 credits. Prerequisite: CEE 371.
3 lecs, one 2-hour lab. Evening exams. J. F. Abel.
Fundamentals of statically indeterminate structures. Moment-area and virtual work methods of displacement computation. Matrix force and stiffness methods. Moment distribution analysis. Influence lines. Computer applications to practical structures.

373 Structural Engineering III Fall. 4 credits. Prerequisites: CEE 372 or permission of instructor; CEE 376 and Engr 261 are also required, but may be taken concurrently.
Evening exams. T. Peköz.
Continues the study of the behavior and design of steel and concrete members and structures. Structural elements, connections, and systems. Plastic analysis of steel frames.

374 Structural Engineering IV Spring. 4 credits. Prerequisite: CEE 373.
M. D. Grigoriu.
Intended to develop an understanding of the structural design process. Comprehensive design project. Lectures on preliminary design, composite construction, prestressed concrete, and various structural systems such as bridges, roofs, tall buildings, and seismic design.

375 Structural Behavior Laboratory Spring. 2 credits. Prerequisite (may be taken concurrently instead): CEE 372.
R. N. White.
A laboratory course on behavior of structures, utilizing small-scale models. Elastic, inelastic, and nonlinear behavior of structural components and systems. Projects.

376 Engineering Materials Fall. 3 credits.
2 lecs, 1 lab. F. O. Slate.
Engineering properties of concrete, steel, wood, and other structural materials. Design characteristics and significance of test results of materials used in engineering works. Extensive laboratory testing and report writing.

426 Seminar in Technology Assessment Spring. 3 credits. Open to graduate students and upperclass undergraduates.
N. Orloff.
An interdisciplinary seminar dealing with the social consequences of technological developments and means by which technology can be guided in socially beneficial directions.

[**430 Descriptive Hydrology** Spring. 2 credits. Intended for non–engineering majors. Prerequisite: permission of instructor. Not offered 1982–83.
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, ground water, surface runoff, floods, and droughts.]

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.
Introduction to nontechnical aspects of engineering practice: legal, financial, social, and ethical aspects; personnel management; communications; professional organizations.

601 Numerical Solutions to Civil Engineering Problems Fall. 3 credits.
Introduction to numerical and computer methods through consideration of typical problems drawn from a number of disciplines within civil and environmental engineering. Topics include computer use, computer programming, data handling, numerical analysis at the graduate level, and the role of computing in the civil enginering profession.

610 Remote Sensing: Fundamentals Fall. 3 credits. Prerequisite: permission of instructor.
2 lecs, 1 lab. W. R. Philipson.
Fundamentals of sensing earth resources with sensors of electromagnetic radiation. Coverage includes sensors, sensor and ground-data acquisition, data analysis and interpretation, and project design.

611 Remote Sensing: Environmental Applications Spring. 3 credits. Prerequisite: permission of instructor.
2 lecs, 1 lab. W. R. Philipson.

Applications of remote sensing in various environmental disciplines. Emphasis is on the use of aircraft and satellite imagery for studying surface features in engineering, planning, agriculture, and natural resource assessments.

[612 Physical Environment Evaluation Fall. 3 credits. Prerequisite: permission of instructor. Not offered 1982–83.
2 lec, 1 lab. T. Liang.
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.
2 lecs, 1 lab. T. Liang.
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.
2 lecs, 1 lab. T. Liang.
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.

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

617 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.

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 Spring. 1 credit. S-U grades only.
W. R. Philipson.
Presentation and discussion of current research, developments, and applications in remote sensing. Lectures by Cornell staff and invited specialists from government and industry.

[624 Legal Process Spring. 3 credits. Limited to graduate students and upperclass undergraduates. Not offered 1982–83.
N. Orloff.
An introduction to the structure and operation of our legal system. Development of legal skills and the ability to do one's own basic legal research.]

[625 Environmental Law I Fall. 4 credits. Limited to graduate students and seniors; other undergraduates with permission of instructor. Not offered 1982–83.
N. Orloff.
An introduction to how the legal system handles environmental problems. Study of federal statutes such as the National Environmental Policy Act, the Clean Air Act, and the Clean Water Act; the regulations issued to implement them; and the important judicial decisions that have been handed down under each.]

626 Environmental Law II Spring. 3 credits. Limited to graduate students and seniors; other undergraduates with permission of instructor.
N. Orloff, R. Booth.
Analysis of additional components of environmental law, such as those pertaining to toxic substances, hazardous wastes, and management of public lands.

628 Public Systems Analysis Spring. 3 credits. Prerequisite: CEE 323 or an introductory optimization course.
C. A. Shoemaker.
Use of systems analysis in engineering design for solutions to public-sector and environmental problems. Applications to water-resource, energy-production and facility-location problems.

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

630 Advanced Fluid Mechanics Fall. 3 credits. Prerequisite: CEE 331.
3 lecs. P. L.-F. Liu.
Introduction to tensor analysis, conservation of mass, momentum and energy from a rigorous point of view. 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 Dynamic Oceanography Fall. 3 credits. Prerequisite: CEE 331. Not offered 1982–83.
P. L.-F. Liu.
The statics and dynamics of oceans and lakes. Currents in homogeneous and stratified bodies of water; tidal motions; waves in a stratified ocean.]

632 Analytical Hydrology Fall. 3 credits. Prerequisite: CEE 331.
W. H. Brutsaert.
Physical and statistical analysis related to hydrologic processes. Hydrometeorology and evaporation. Infiltration and base flow. Surface runoff and channel routing. Linear and nonlinear hydrologic systems analysis. Storage routing and unit hydrograph theory.

[633 Flow in Porous Media and Ground Water Spring. 3 credits. Prerequisite: CEE 331. Not offered 1982–83.
W. H. Brutsaert.
Fluid mechanics and equations of single-phase and multiphase flow; methods of solution. Aquifer hydraulics, pumping wells; drought flows; infiltration, ground-water recharge; land subsidence: sea-water intrusion, miscible displacement; transient seepage in unsaturated materials.]

634 Engineering Micrometeorology Spring. 3 credits. Prerequisite: CEE 331.
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, urban climatology, interaction of wind and structures, snow and ice problems.

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 I Fall. 3 credits. Prerequisite: CEE 331.
3 lecs. G. H. Jirka.
Introduction to mass and heat-transport processes due to pollutant discharges into the environment. Turbulent diffusion equation and its solution for instantaneous and continuous releases. Concept of longitudinal dispersion in shear flow. Applications to pollutant-transport prediction in lakes, rivers, estuaries, and coastal zones, as well as the atmosphere. Relative role of hydrodynamic transport to reaction kinetics. Exchange processes for mass and heat at the air-water interface. Convective transport due to density currents. Jet mixing and the design of outfall structures.

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. Credit variable.
Staff.
Special topics in fluid mechanics, hydraulic engineering, or hydrology.

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

641 Retaining Structures and Slopes Spring. 3 credits. Prerequisite: CEE 341.
3 lecs, optional tutorial. T. D. O'Rourke, F. H. Kulhawy.
Earth pressure theories. Design of rigid, flexible, braced, tied back, slurry, and reinforced earth walls. Stability of excavation, cut, and natural slopes.

642 Highway Engineering (also Agricultural Engineering 491) Fall. 3 credits. Prerequisite: CEE 341 or permission of instructor.
2 lecs, 1 lab. L. H. Irwin.
See Agricultural Engineering 491 for course description.

643 Bituminous Materials and Pavement Design (also Agricultural Engineering 492) Spring. 3 credits. Prerequisite: CEE 642 or permission of instructor.
2 lecs, 1 lab. L. H. Irwin.
See Agricultural Engineering 492 for course description.

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 this subject area.

648 Seminar in Geotechnical Engineering Fall or spring.
Staff.
Presentation and discussion of topics of 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.

651 Microbiology of Water and Wastewater Fall. 2 credits. Prerequisites: one semester of college chemistry.
J. M. Gossett.
Microbiological phenomena pertinent to analysis of natural systems and design of engineered microbial processes in pollution control. Quantitative aspects of growth and substrate utilization will be stressed.

653 Chemistry of Water and Wastewater Fall. 3 credits. Prerequisite: one semester of college chemistry or permission of instructor.
3 lec-recs. J. M. Gossett.
Principles of physical, organic, inorganic, and biological chemistry applicable to the understanding, design, and control of water and wastewater treatment processes and to reactions in receiving waters.

654 Aquatic Chemistry Spring. 3 credits. Prerequisite: CEE 653 or Chemistry 287–288.
3 lecs. J. J. Bisogni.
Development of fundamental concepts of chemical equilibria and application to natural aquatic systems, as well as to water and wastewater treatment systems. Topics include chemical thermodynamics, acid-base reactions, oxidation-reduction, coordination chemistry, biologically mediated reactions, and interfacial phenomena. Emphasis is placed on phenomena, mathematical solution of chemical equilibria, and their application to the prediction and management of water quality.

655 Industrial Waste Management Spring. 3 credits. Prerequisites: CEE 351 and 653 or permission of instructor.
3 lec-discs. R. C. Loehr.
An analysis of the treatment and disposal of industrial wastes, primarily wastewaters. Regulatory and legal aspects; pretreatment; treatment and disposal processes for conventional, nonconventional, and toxic pollutants; industrial-waste survey; case studies of specific industries; opportunities for recycle and reuse. Emphasis is on an understanding of the constraints on industrial-waste discharges and the processes and approaches to meet those constraints.

656 Environmental Quality Management Fall; spring on demand. 3 credits (4 with approval of instructor). For upperclass or graduate students. May not be offered 1982–83.
2 lec-discs. L. B. Dworsky.
An introduction to environmental quality management; nature, cause, and control of environmental problems; interaction of physical, social, and cultural environments; emphasis on the interdependent social, economic, developmental, and environmental issues confronting society.

658 Sludge Treatment, Utilization, and Disposal Spring. 3 credits. Prerequisites: CEE 351 and 653 or permission of instructor.
R. I. Dick.
An analysis of the quantity and quality of residues produced from water and wastewater treatment facilities as a function of process design and operation; the alternatives for reclamation or ultimate disposal of residues with assessment of potential environmental impacts and factors influencing the magnitude of those impacts; the fundamental factors influencing performance of treatment processes for altering sludge properties prior to ultimate disposal; and considerations in selection and integration of sludge management processes to approach optimal design.

659 Environmental Quality Engineering Seminar
Fall or spring. 1 credit. Open to undergraduates with permission of the instructor.
Presentation and discussion of current topics and problems in sanitary engineering and environmental quality engineering.

660 Urban Transportation Planning Fall. 4 credits.
G. P. Fisher.
The urban transportation problem: its roots, manifestations, and implications; the systems analysis approach to transportation; demand and supply side of transportation; the urban transportation planning process and its modeling components; generation and evaluation of alternatives. A laboratory period is designed for study-team projects using computerized planning system packages.

661 Travel Demand Theory and Applications
Spring. 3 credits. Prerequisite: CEE 660 or permission of instructor.
A. H. Meyburg.
This course concentrates on new methods for estimating and predicting travel demand. In particular, it considers techniques based on a treatment of the individual as an economic or psychological decision-making unit. Theoretical background to the models, empirical estimation, measurement of attributes, and practical applications are considered. Practical problems and directions of present and future research is outlined. Survey sampling is introduced.

663 Transportation Systems Analysis Fall. 3 credits. Prerequisites: CEE 361, OR&IE 320 or equivalent.
M. A. Turnquist.
Application of operations research and systems analysis techniques to transportation systems, both passenger and freight. Network flows. Design of networks, routes, and schedules. Terminal operation and design.

[**664 Transportation Systems Design** Spring. 3 credits. Prerequisite: CEE 663. Not offered 1982–83.
M. A. Turnquist.
Advanced techniques for design of transportation systems, including networks of fixed facilities and route networks. Time-staging of improvements, use of low-capital cost options, and the role of demonstration projects. Evaluation of alternative designs.]

666 Transportation Economics Spring. 3 credits. Prerequisite: CEE 321 or equivalent.
A. H. Meyburg.
Economic analysis of freight and passenger transportation systems. Pricing and regulation. Elements of cost-benefit analysis and evaluation of public investment and subsidization. Consideration of national transportation policy.

668 Operations, Design, and Planning of Public Transportation Systems Spring. 3 credits. Recommended: CEE 361 or CEE 660.
M. A. Turnquist.
Financing and organization of mass transportation. Design of route networks. Scheduling of services. Use of computer-aided design methods. Fare policy and planning for provision of integrated services. The role of innovative technology.

[**669 Freight Transportation** Spring. 3 credits. Recommended: CEE 361 or CEE 660. Not offered 1982–83.
G. P. Fisher.
Transportation-planning methodology for interurban and intraurban freight movements. Relationship to the urban transportation-planning process. Facilities design. Problem identification, solution strategies, analysis techniques. Freight demand analysis. Alternative technologies in view of energy, efficiency, and environmental impacts. Economic regulation.]

670 Timber Engineering Spring. 1 credit. Prerequisite: CEE 373.
R. N. White.
Structural properties of timber. Timber tension members, beams, and beam-columns. Glued-laminated timber design. Connection behavior and design. Special timber structural systems.

672 Fundamentals of Structural Mechanics Fall. 3 credits. Prerequisite (may be taken concurrently instead): CEE 373.
M. D. Grigoriu.
Theory of elasticity, energy principles, plate flexure, failure theories, inelastic stress-strain relationships, stress concentration, introduction to fracture, fatigue.

673 Advanced Structural Analysis Fall. 3 credits. Prerequisites: CEE 372 and computer programming.
A. R. Ingraffea.
Direct stiffness and flexibility methods in matrix formulation, use of standard analysis programs, error detection, substructuring, and special analysis procedures.

674 Structural Model Analysis and Experimental Methods Fall. 3 credits.
2 lecs, 1 lab. R. N. White.
Dimensional analysis and similitude. Model materials, fabrication, loading, and instrumentation techniques. Experimental stress analysis.

675 Advanced Plain Concrete Spring. 3 credits. Prerequisite: CEE 367 or equivalent.
2 lecs, conferences. F. O. Slate.
Topics such as history of cementing materials, air entrainment, light-weight aggregates, petrography, durability, chemical reactions, properties of aggregates, and construction. Relationships among internal structure, physical properties, chemical properties, and mechanical properties.

[**676 Structure and Properties of Materials**
Spring. 3 credits. Limited to graduate students in engineering or physical sciences, or undergraduates by permission of instructor. Offered alternate years. Not offered 1982–83.
2 lecs, conferences. F. O. Slate.
Internal structure from amorphous to crystalline state. Forces holding matter together versus forces causing deformation and failure. Correlation of internal structures with physical and mechanical properties. Applications to various engineering materials.]

678 Low-Cost Housing Primarily for Developing Nations Spring. 3 credits. Offered alternate years.
2 lecs, conferences. F. O. Slate.
A multidisciplinary course. Students work intensively, usually in their own discipline, for a term project while also being introduced to problems and approaches of other disciplines. Engineers investigate the technological aspects of the subject and other aspects that influence technological decisions, such as cultural and economic factors.

[**679 Low-Cost Housing for Developing Nations —Workshop for Physical Planning, Site Selection, and Design** Spring. A mixed class of advanced civil engineering and architecture students. Offered alternate years. Not offered 1982–83.
F. O. Slate.
Discussions and workshops on physical planning, site selection, choice of materials, and detailed design of individual structures and groupings.]

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

691 Water Resources Problems and Policies
Fall. 3 credits. Intended primarily for graduate engineering and nonengineering students but open

to qualified upperclass students. Prerequisite: permission of instructor.
Lec-disc. L. B. Dworsky.
Historical and contemporary perspectives of water problems, organization, and public policies.

692 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. Lectures examine Box-Jenkins, fractional-Brownian noise, and other streamflow models; drought- and flood-frequency estimation; analysis of simulation output; parameter estimation and Bayesian inference.

[**693 Water Quality Modeling** Spring. 3 credits. Prerequisites: CEE 323 or Agricultural Engineering 475. Not offered 1982–83.
D. P. Loucks.
Predictive models of the behavior of biological and chemical substances in bodies of water and in surface runoff. Regional management of water quality.]

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

695 Water Resources Systems Planning II Spring. 3 credits. Prerequisites: CEE 304 and CEE 694 or permission of instructor.
J. R. Stedinger, D. P. Loucks.
Optimization and simulation models for water-resource planning under uncertainty. Basics of stochastic hydrologic modeling and stochastic river-basin and reservoir models.

721 Environmental and Water Resources Systems Analysis Design Project On demand. Credit variable. Prerequisite: permission of instructor. May extend over two semesters.
Staff.
Design or feasibility study of environmental or water resources systems, 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. Credit variable. Prerequisite: permission of instructor. Preparation must be suitable to the investigation to be undertaken.
Investigations of particular environmental or water resources systems problems.

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

730 Coastal Engineering II Fall. 3 credits. Prerequisite: CEE 635.
3 lecs. P. L.-F. Liu.
Review of gravity wave theories, applicability of different wave theories to engineering problems, wave-energy transmission, tsunamis, boundary-value problems in wave hydrodynamics, behavior of submerged and floating bodies, harbor agitations, ship waves.

[**731 Environmental Fluid Mechanics II** Spring. 3 credits. Prerequisite: CEE 636 or permission of instructor. Offered alternate years. Not offered 1982–83.
3 lecs. G. H. Jirka.
Mechanics of discretely and continuously stratified fluids: internal waves, density currents, blocking, selective withdrawal, and internal jumps. Interfacial stability and mixing. Observed characteristics of turbulent fluid flow in environmental applications, including interaction with buoyancy. Integral techniques for self-similar flows: jets, plumes, and mixing layers. Experimental approaches to environmental fluid problems.]

732 Unsteady Hydraulics Spring. 3 credits. Prerequisite: CEE 332 or permission of instructor.
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.

[**733 Environmental Planning and Operation of Energy Facilities** Spring. 3 credits. Mixed lecture and seminar format. Prerequisites: CEE 636 or equivalent. Not offered 1982–83.
G. H. Jirka.
Survey of analytical methodologies for predicting and controlling the environmental impacts of individual energy facilities or of energy systems. Estimation of construction and operating impacts: pollutant sources, models for pollutant dispersal, modeling the relationships of pollutant concentration and ecological, health, and socioeconomic damages. Pollutant-abatement strategies and transient releases techniques. Models for regional energy-facility siting.]

[**734 Experimental Methods in Hydraulics** On demand. 2 credits. Prerequisite: CEE 331. Not offered 1982–83.
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.

740 Engineering Behavior of Soils Fall. 3 credits. Prerequisite: CEE 341.
3 lecs. I. Ishibashi.
Detailed study of physiochemical nature of soil. Stress states and stress-strain-time behavior. In-depth evaluation of the strength, compressibility, and permeability of natural soils. Study of special deposits such as sensitive, organic, frozen, and man-made soils.

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

742 Graduate Soil Mechanics Laboratory Fall. 3 credits. Prerequisite: CEE 740.
I. Ishibashi.
Laboratory measurement of soil properties, from introductory to advanced techniques. Emphasis on strength, compressibility, and permeability tests. Critical evaluation of laboratory methodology.

[**744 Advanced Foundation Engineering** Spring. 3 credits. Prerequisite: CEE 640. Not offered 1982–83.
3 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. 3 credits. Prerequisite: permission of instructor.
3 lecs. I. Ishibashi.
Principles of vibration under harmonic and transient loading. Wave propagation. Dynamic response of soils and its measurement. Analytical models for harmonic, transient, and earthquake loading. Design examples of foundations and embankments.

746 Embankment Dam Engineering Spring. 2 credits. Prerequisites: CEE 641 and 741, or permission of instructor.
2 lecs. F. H. Kulhawy.
Principles of analysis and design for earth and rockfill dams. Materials, construction methods, internal and external stability, seepage and drainage, performance monitoring, abutment and foundation evaluation. Introduction to tailings dams.

[**747 Case Studies in Geotechnical Engineering** Spring. 3 credits. Prerequisites: CEE 641 and 741. Not offered 1982–83.
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.
2 lecs. F. H. Kulhawy, T. D. O'Rourke.
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.

752 Water Quality Laboratory Fall. 1 credit. Enrollment limited. Prerequisites: CEE 653 (students may enroll concurrently in CEE 653) and permission of instructor.
J. M. Gossett.
Laboratory methods for analysis of pollutants in water and wastewater.

755 Environmental Engineering Processes I Fall. 3 credits (4 with lab). Prerequisite: CEE 653 or permission of instructor.
3 lecs, 1 lab. L. W. Lion.
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. Residuals control and treatment. Pertinent laboratory studies.

756 Environmental Engineering Processes II Spring. 3 credits (4 with lab). Prerequisite: CEE 755 or permission of instructor.
3 lecs, 1 lab. 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. Pertinent laboratory studies.

757 Design Project in Sanitary Engineering On demand. Variable credit. Prerequisite: CEE 351 or equivalent.
Staff.
The student chooses or is assigned a problem in the design of water or wastewater treatment, pollution-control facilities, or a laboratory project.

758 Sanitary Engineering Research On demand. Variable credit. Prerequisites will depend on the particular investigation to be undertaken.
Staff.
For the student who wants to study a problem in greater depth than is possible in formal courses. Study may be any combination of literature, laboratory, or computational research.

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

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.

763 Transportation Colloquium Fall or spring. 1 credit.
Lectures in various topics related to transportation planning and analysis.

764 Special Topics in Transportation Fall or spring. Variable credit.
Staff.
Consideration of subject matter not covered in depth in regular courses. Topics vary from year to year but may include such topics as terminal operations, airport planning and design, traffic-flow theory, marine transportation.

770 Engineering Fracture Mechanics Spring. 3 credits. Prerequisite: CEE 772 or permission of instructor. Offered alternate years.
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. Laboratory techniques for fracture toughness testing of metals, concrete, and rock.

771 Structural Stability: Theory and Design Spring. 3 credits.
T. Peköz.
Analysis of elastic and plastic stability. Determination of buckling loads and postbuckling behavior of columns. Solid and open web columns with variable cross section. Beam columns. Frame buckling. Torsional-flexural buckling. Lateral buckling of beams. Buckling loads and postbuckling behavior of plates, shear webs, and shells. Critical discussion of current design specification.

772 Finite-Element Analysis Spring. 3 credits. Prerequisites: CEE 672 and 673, or permission of instructor.
J. F. Abel.
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 Fall. 3 credits. Prerequisite: CEE 373. May not be offered 1982–83.
M. D. Grigoriu.
Review of probability theory, practical measures for structural reliability, second-moment reliability indices, probability models for strength and loads, load combinations, probability-based design codes, reliability of structural systems with applications, introduction to random vibration, applications to wind and seismic design.

774 Prestressed Concrete Structures Fall. 3 credits. Prerequisite: CEE 373, Recommended: CEE 374.
3 lecs. A. H. Nilson.
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 and compression members, frameworks, bridges.

775 Advanced Reinforced Concrete Spring. 3 credits. Prerequisite: CEE 373. Recommended: CEE 374.
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 373.
W. McGuire.
Behavior and design, with emphasis on connections, plate girders, and cold-formed steel structures. Torsion of steel members. Fatigue and fracture.

777 Advanced Behavior of Metal Structures Spring. 3 credits. Prerequisite: CEE 373.
W. McGuire.
Behavior of beams, beam-columns, and single and multistory frames. Analysis and design of tall-building systems. Cable-supported structures.

778 Shell Theory and Design Spring. 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 Design for Dynamic Loads Spring. 3 credits.
P. Gergely.
Modal analysis, numerical methods, and frequency-domain analysis. Introduction to earthquake-resistant design.

[**780 Optimum Structural Design** Fall. 3 credits. Offered alternate years. Not offered 1982–83.
Design of minimum wieght or cost structures. Includes full-stressed design, classical, minimization procedures, and mathematical programming methods.]

[**781 Numerical Methods in Structural Engineering** Fall. 3 credits. Prerequisites: CEE 672 and 673. Offered alternate years. Not offered 1982–83.
J. F. Abel.
Numerical techniques for structural and geotechnical engineering, such as residual, variational, finite-difference, and finite-element methods. Selected numerical analysis topics and solution algorithms with emphasis on linear equations and eigenvalue problems.]

[**782 Advanced Topics in Finite-Element Analysis** Fall. 3 credits. Prerequisite: 772. Offered alternate years. Not offered 1982–83.
J. F. Abel.
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.
F. O. Slate.
Individual projects or reading and study assignments involving engineering materials.

784 Design Project in Structural Engineering Fall or 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 further than can be done 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.

810 Thesis—Remote Sensing Fall and 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.

851 Thesis—Environmental Engineering Fall and 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.

880 Thesis—Structural Engineering Fall and 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.

Computer Science

The Department of Computer Science is organized as a department in both the College of Arts and Sciences and the College of Engineering.

100 Introduction to Computer Programming (also Engineering 105) Fall, spring, summer. 4 credits. S-U grades optional. Students who plan to take both Com S 101 and 100 must take 101 first.
2 lecs, 1 rec (optional). 3 evening exams, final.

An introduction to elementary computer programming concepts. Emphasis is on techniques of problem analysis and algorithm and program development. The subject of the course is programming, not a particular programming language. The principal programming language used is PL/I; FORTRAN is introduced and used for final problems. 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 Spring, summer. 3 credits. S-U grades optional. Credit cannot be granted for both Com S 100 and 101 unless 101 is taken first.
2 lecs, 1 rec.
Introduction to computer science and programming for students in nontechnical areas. 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 PL/I programs using the Cornell Program Synthesizer. The amount of programming is about half of that taught in Computer Science 100. Each student writes a term paper on some aspect of computing. The aims of the course are to make the student an intelligent consumer of what the computer has to offer and to develop an appreciation of algorithmic thinking.

211 Computers and Programming (also Engineering 211) Fall, spring, summer. 3 credits. Prerequisite: Com S 100 or equivalent programming experience.
2 lecs, 1 rec.
Intermediate programming in a high-level language and introduction to computer science. Topics include program development, invariant relations, block structure, recursion, introduction to data structures, analysis of algorithms, and a brief introduction to machine architecture and machine-level programming. PL/I is the principal programming language used.

280 Discrete Structures Fall. 4 credits. Prerequisite: Com S 211 or permission of instructor.
3 lecs.
Covers mathematical aspects of programming and computing. Topics will be chosen from the following: mathematical induction; logical proof; combinatorics and discrete mathematics covering manipulation of sums, recurrence relations, and generating function techniques; introduction to recursive functions, relations, partially ordered sets, and the predicate calculus.

[305 Social Issues in Computing Fall. 3 credits. Prerequisite: Com S 100, 101, or permission of instructor. Not offered 1982–83.
2 lecs.
Economic, political, legal, and cultural impact of computers and computer-related technology; the role of computers in coordinating diversity and reducing disorder; the effect of computers on the individual; data banks and privacy; machine creativity and machine intelligence.]

314 Introduction to Computer Systems and Organization Fall, spring, summer. 4 credits. Prerequisite: Com S 211 or equivalent.
2 lecs, 1 lab.
Logical structure of digital computers, representation of information, machine-assembly language, the input-output channel, hierarchical storage systems, and microprogramming.

321 Numerical Methods (also Engineering 321) Fall, spring. 4 credits. Prerequisites: Mathematics 221 or 293, and knowledge of FORTRAN equivalent to what is taught in Com S 100.
3 lecs.
Students solve representative problems by programming appropriate algorithms and using library programs. Numerical methods for systems of linear equations, interpolation, integration, ordinary differential equations, nonlinear equations, optimization, and linear least squares.

410 Data Structures Fall, summer. 4 credits. Prerequisite or corequisite: Com S 314. Recommended: Com S 280.
3 lecs.
Lists, trees, graphs, arrays, and other forms of data structure and their implementation. Relation between language and data structure. Dynamic storage allocation and memory management. Detailed study of searching and sorting methods. Analysis to determine the more efficient algorithm in a given situation.

414 Systems Programming and Operating Systems Spring. 4 credits. Prerequisite: Com S 314 or permission of instructor.
3 lecs.
The logical design of systems programs with emphasis on multiprogrammed operating systems. Covers input-output methods, process synchronization, memory management, sharing, file systems. Case studies. Project to implement a small system.

417 Interactive Computer Graphics (also Architecture 334) Spring. 4 credits. Enrollment limited for 1982–83. Requires instructor's signature. Prerequisite: Com S 314.
2 lecs, 1 lab.
Introduction to the software and hardware concepts of interactive computer graphics. Topics include input methods, graphic data structures, geometric modeling, surface description methods, hidden-line/hidden-surface algorithms, image processing, color perception, and realistic image synthesis. Examples of computer-aided design applications are presented. Assignments consist of hands-on experience on storage tube, vector refresh, and color raster displays. Course makes use of the Computer-Aided Design Instructional Facility.

432 Introduction to Database Systems Spring. 4 credits. Prerequisite: Com S 211.
2 lecs, 1 rec.
Introduction to modern database systems, including data models, processing and query languages, file organization schemes and problems associated with distributed and concurrent processing.

481 Introduction to Theory of Computing Fall. 4 credits. Prerequisites: Com S 211 and 280, equivalent mathematics, or permission of instructor.
3 lecs.
Introduction to modern theory of computing. Covers automata theory, formal languages, effective computability.

482 Introduction to Analysis of Algorithms Spring. 4 credits. Prerequisites: Com S 410 and 481 or permission of instructor.
3 lecs.
Major paradigms used in the creation and analysis of algorithms. Combinatorial algorithms, computational complexity, NP-completeness, and intractable problems.

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.
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.

611 Advanced Programming Languages Fall. Prerequisites: Com S 410 and 481 or permission of instructor.
3 lecs.
Introduction to techniques for formal specification of programming languages and data types, including term rewriting systems and Scott's denotational techniques; use of formal semantics in comparing and classifying languages; other advanced concepts including logic programming, functional programming, and data-flow languages.

612 Translator Writing Spring. 4 credits. Prerequisites: Com S 410 and 481 or permission of instructor.
3 lecs.
Discussion of the models and techniques used in the design and implementation of compilers. Topics include lexical analysis in translators, compilation of arithmetic expressions and simple statements, specifications of syntax, algorithms for syntactic analysis, code generation and optimization techniques, bootstrapping methods, and translator writing systems.

613 Concurrent Programming and Operating Systems Principles Fall. 4 credits. Prerequisites: Com S 414 and 600 or permission of instructor.
3 lecs.
Covers advanced techniques and models of concurrent systems. Synchronization of concurrent processes; parallel programming languages; deadlock; verification.

[615 Machine Organization Spring. 4 credits. Prerequisite: Com S 314 or permission of instructor.
3 lecs. Not offered 1982–83.]

621–622 Numerical Analysis 621, fall; 622, spring. 4 credits each term. Prerequisites: Com S 321 and Mathematics 411 and 431.
3 lecs.
The analysis and implementation of algorithms for the numerical solution of basic mathematical problems. Emphasis is placed on the estimation of error, the analysis of stability, and how to design efficient and reliable numerical algorithms. During both terms the student solves representation problems by writing original programs and by making use of high quality, state-of-the-art software. Fall term: direct methods for linear equations, interpolation, least squares and polynomial approximation, nonlinear equations, and optimization. Spring term: Quadrature, ordinary and partial differential equations, methods for sparse systems of linear equations, and eigenvalue problems.

623 Short Course on Linear and Nonlinear Least Squares 2 credits. Fall. Prerequisite: Com S 321 or permission of instructor. Not offered every year.
Topics include orthogonal matrix methods for the least squares (LS) problem, using LINPACK to solve the LS problem, the Lawson-Hanson codes, variable projection methods for fitting sums of exponentials, and software for general nonlinear least squares problems.

624 Short Course on Spline Approximation 2 credits. Fall. Prerequisite: Com S 321 or permission of instructor. Not offered every year.
Practical introduction to curve and surface fitting with splines. Topics include interpolation with cubic splines, parabolic spline interpolation, B-splines, smoothing, and splines under tension. The deBoor spline package is extensively used.

632 Database Systems Fall. 4 credits. Prerequisites: Com S 410 and either 432 or permission of instructor.
2 lecs.

Review of hierarchical, network, and relational database models. Relational database theory. Implementation issues: query optimization, data integrity and protection, concurrency control, crash recovery. Distributed database systems. Database machines. Current research topics in database systems will be emphasized.

635 Information Organization and Retrieval Spring. 4 credits. Prerequisite: Com S 410 or equivalent.
2 lecs.
Introduction to information retrieval. File organization and search algorithms. Statistical analysis of written texts. Automatic classification of information; language and content analysis of texts. Interactive filing and retrieval applied to documents and business correspondence. Automatic libraries, office automation systems, question-answering systems, and database retrieval.

643 Design and Analysis of Computer Networks Fall. 4 credits. Prerequisite: Com S 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 the presentation and application layers will also be discussed.

681 Analysis of Algorithms Fall. 4 credits. Prerequisite: Com S 481 or permission of instructor.
3 lecs.
Major paradigms used in the creation and analysis of algorithms. Complexity measures, advanced data structures, algorithms on graphs, lower bounds, reducibilities, and polynomial complete problems. Special topics in analysis of algorithms. This course includes the contents of Com S 482.

682 Theory of Computing Spring. 4 credits. Prerequisite: Com S 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. For staff, visitors, and graduate students interested in computer science.
1 sem.
A weekly meeting for the discussion and study of important topics in the field.

711 Theory of Programming Languages Spring. 4 credits. Prerequisites: Com S 481 and 611. Not offered every year.
2 lecs.
Advanced topics in formal semantics. Topics may include mathematical semantics, program verification systems, application of formal semantics to language design, variable-free languages, and correctness of implementations.

712 Theoretical Aspects of Compiler Construction Spring. 4 credits. Prerequisites: Com S 612. Not offered every year.
2 lecs.
Formal methods of syntactic analysis, including precedence, bounded context, and LR techniques. General parsing methods and their time-spaced complexity. Noncanonical parsing techniques. Formal methods of object code optimization.

713 Seminar in Operating Systems Fall, spring 4 credits. Prerequisite: Com S 613 or permission of instructor.
1 sem.
Discussion of contemporary issues in operating systems.

719 Seminar in Programming Fall, spring. 4 credits. Prerequisite: Com S 611 or permission of instructor.
1 sem.

721 Advanced Numerical Analysis Fall. 4 credits. Prerequisite: Com S 621 or 622 or permission of instructor. Alternates with Com S 722. Not offered every year.
2 lecs.
Topics are chosen at instructor's discretion. Sample topics include matrix computations, numerical optimization, numerical solution of ordinary differential equations and partial differential equations.

722 Advanced Numerical Analysis Spring. 4 credits. Alternates with Com S 721. Not offered every year. See description of Com S 721, above.
2 lecs.

729 Seminar in Numerical Analysis Fall, spring. 4 credits. Prerequisite: permission of instructor.

[**733 Selected Topics in Information Processing (also OR&IE 789)** Not offered 1982–83.]

734 Seminar in File Processing Fall. Credit and hours to be arranged. Prerequisite: Com S 733.

739 Seminar in Information Organization and Retrieval Fall, spring. Credit and hours to be arranged. Prerequisite: Com S 635.
Hours to be arranged.

749 Seminar in Systems Modeling and Analysis Fall, spring. 4 credits. Prerequisite: permission of instructor.
1 sem.
Discussion of advanced topics in modeling and analysis of computer systems and networks, with emphasis on performance.

781 Advanced Theory of Computing Fall. 4 credits. Prerequisites: Com S 681 and 682, or permission of instructor. Alternates with Com S 782. Not offered every year.
At instructor's discretion, advanced topics, possibly including automata, computability, computational complexity, program schemata, symbolic computation, and analysis of algorithms.

782 Advanced Theory of Computing Spring. 4 credits. Alternates with Com S 781. Not offered every year.

789 Seminar in Theory of Algorithms and Computing Fall, spring. 2–4 credits. Prerequisite: permission of instructor.
1 sem.

790 Special Investigations in Computer Science Fall, spring. Prerequisite: permission of a computer science adviser.
Independent research.

890 Special Investigations in Computer Science Fall, spring. Prerequisite: permission of a computer science adviser.
Master's degree research.

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

Electrical Engineering

210 Introduction to Electrical Systems (also Engineering 210) Fall or spring. 3 credits. Prerequisites: Mathematics 192 and Physics 112.
3 lec-recs.
Circuit elements and laws; natural response of linear systems; impedance and pole-zero concepts; complex frequency and phasors; forced response and power systems; transfer function and frequency response; low-frequency terminal characteristics of diodes, triodes, and transistors; linear models of electronic devices; bias circuits and frequency response of amplifiers; operational amplifiers, feedback, and oscillators.

230 Introduction to Digital Systems Fall or spring. 3 credits.
2 lecs, 5 lab experiments.
Introduction to basic analysis and design techniques and methodology of digital and computer systems. Boolean algebra; integrated circuit components used in digital-system implementation; codes and number systems; logic design of combinational circuits; logic design of sequential circuits; microprocessors and microcomputers; application of microprocessors and microcomputers to digital-system design.

301 Electrical Signals and Systems I Fall. 4 credits. Prerequisites: Elec E 210 and Mathematics 294 or equivalents.
3 lecs, 1 rec-computing session.
Formulation of circuit equations, steady-state response; Laplace transform and applications; system functions; state description of linear systems; natural modes, initial conditions, forced response; two-port circuit descriptions; models for active circuits.

302 Electrical Signals and Systems II Spring. 4 credits. Prerequisite: Elec E 301.
3 lecs, 1 rec-computing session.
Single-sided and bilateral Laplace transforms; applications of complex functions and contour integration to system response; stability criteria; Fourier series and transforms; discrete and fast Fourier transforms; sampling.

303 Electromagnetic Theory I Fall. 4 credits. Prerequisites: Physics 214 and Mathematics 294.
3 lecs, 1 rec-computing session.
Foundation of electromagnetic theory. Topics include Maxwell's equations; boundary conditions and the Laplace equation; plane waves, wave propagation and reflection at boundaries, the Poynting theorem; guided TEM, TM, and TE waves, impedance transformation, and matching. Introduction to simple antenna systems.

304 Electromagnetic Theory II Spring. 4 credits. Prerequisites: Elec E 301 and 303.
3 lecs. 1 rec-computing session.
Fundamentals of electromagnetic theory with emphasis on wave propagation and guidance, radiating systems, and the effects of the medium on transmission. Topics include retarded potentials; relation of radiation fields to source distributions, antenna gain concepts, and techniques in antenna design; wave guide systems, separation of variables, cavities, and losses; propagation in inhomogeneous and anisotropic media, complex permittivity, plasma and magnetic field effects.

306 Fundamentals of Quantum and Solid-State Electronics Spring. 4 credits. Prerequisites: Physics 214, Mathematics 294, and Ele E 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.

310 Probability and Random Signals Spring. 4 credits. Prerequisite: Mathematics 294.
3 lecs, 1 rec-computing session.

Introduction to modeling random phenomena and signals and applications of these models. Topics include concepts of probability, conditional probability, independence, random variables, expectation and random processes. Applications to problems of inference, estimation, and linear system response in communications, computers, control, and pattern classification.

315 Electrical Laboratory I Fall. 4 credits. Prerequisites: Elec E 210 and coregistration 301.
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.

316 Electrical Laboratory II Spring. 4 credits. Prerequisites: Elec E 303 and 315.
2 lecs, 2 labs.
Laboratory studies of solid-state phenomena and devices; experiments illustrating the use of the digital computer in electrical engineering; laboratory studies of high-frequency phenomena and devices; and introduction to AC and DC machinery.

407 Quantum Mechanics and Applications Fall. 4 credits. Prerequisite: Elec E 306.
3 lecs, 1 rec-computing session. R. Liboff.
Review of basic classical and quantum mechanical relations. Harmonic oscillator. Annihilation and creation operators. WKB technique. Superposition principle. Addition of angular momentum. Ladder operators. Clebsch-Gordon coefficients. Radiation from an atom. Selection rules. Pauli principle. Spin-orbit coupling. Spin states. Helium atom and hydrogen molecule. Magnetic resonance. Perturbation theory. The Born approximation. Nearly-free-electron model. Planck radiation law. Interaction of radiation and matter. Density matrix. At the level of *Introductory Quantum Mechanics*, by Liboff.

421 Bioinstrumentation Fall. 3 credits (4 credits with lab). Prerequisites: Ele E 301 and 316.
3 lecs, 1 lab.
The acquisition and processing of biological signals. Topics include electrodes, ion-selective electrodes, temperature transducers, pressure transducers, flow transducers, force transducers, displacement transducers, operational amplifiers, instrumentation amplifiers, analog signal processing, D/A and A/D conversion, and digital processing with minicomputers and microprocessors.

422 Neuroelectric Systems (also Biological Sciences 422) Spring. 3 credits (4 credits with lab). Prerequisite: either Ele E 301 or 421 or Biological Sciences 423 or 496; written permission of instructor required for lab. Offered alternate years.
Disc, demonstration, and lab to be arranged.
Application of microprocessors for neuroelectric data acquisition and systems analysis. Lectures cover electrical activity of single nerve cells, electrodes and instrumentation techniques, analysis of electrophysiological data, and coding principles in the nervous system, as well as appropriate background material for the use of microprocessors in neurobiology. Laboratory exercises provide experience in the actual use of microprocessors.

423 Active and Digital Network Design Fall. 3 credits (4 credits with lab). Prerequisite: Ele E 301.
3 lecs, 1 lab. W. H. Ku.
Design of passive filters and matching networks. Active filter design using operational amplifiers. Design of transistor amplifiers. Digital signal processing. Z-transform and discrete Fourier transform (DFT). Design of nonrecursive and recursive digital filters. Fast Fourier transform (FFT) algorithms.

424 Computer Methods in Electrical Engineering Spring. 4 credits. Prerequisite: Elec E 301.
3 lecs.
Modern techniques for solving electrical engineering problems on the digital computer. Emphasis on efficiency and numerical stability rather than on theoretical implications. Solution of linear and nonlinear algebraic equations; integration; solution of ordinary and partial differential equations; random number generators. Applications to power systems, control systems, communication systems, circuit design, and problems in electrophysics.

426 Advanced Digital Signal Processing Spring. 3 credits (4 credits with lab). Prerequisites: Ele E 423 or permission of instructor.
3 lecs, 1 lab.
Topics include FIR and IIR filter design; the DFT, FFT, and CZT; spectral analysis; data compression; adaptive filters; and speech synthesis. Laboratory involves design of filters using minicomputer-based design tools and implementation of real-time digital filters with microprocessor-based filter systems. At the level of Rabiner and Gold, *Theory and Application of Digital Signal Processing*.

427 Fundamentals of Analog and Discrete-Time Circuits Fall. 4 credits. Prerequisite: Ele E 302.
3 lecs.
Basic theory of analog networks. Linearity, time invariance, causality, passivity, stability. Analogous digital system properties. The scattering formalism. Applications to physical realizability, reactance theorems, dispersion, gain-phase design. Realization of discrete-time circuits.

428 Analog and Discrete-Time Circuit Applications Spring. 4 credits. Prerequisite: Ele E 423, 427, or equivalent.
3 lecs.
Synthesis of analog transducers. Analog and digital transfer functions: maximally flat, Chebyshev, eliptic. Gain-bandwidth theory. Transmission-line properties with applications to microwave circuit design and relation to digital filters.

430 Introduction to Lasers and Optical Electronics 4 credits. Prerequisite: Ele E 306 or equivalent (such as Physics 443).
2 lecs, 1 lec-rec, 1 lab.
An introduction to stimulated emission devices such as masers, lasers, and optical devices based on linear and nonlinear responses to coherent fields. Material discussed, based on quantum mechanical results, employs phenomenological theories and stresses applications to modern devices. Discussions of applications include the operating principles of a variety of important lasers, crystal optics with application to electro-optic and acousto-optic modulators, and an introduction to integrated optics. Labs present an opportunity to work with a variety of the lasers and processes discussed in lectures.

431–432 Electronic Circuit Design 431, fall; 432, spring. Fall, 4 credits; spring, 3 or 4 credits. Prerequisites: Ele E 230 and 316.
3 lecs, 1 optional lab. N. H. Bryant.
Design techniques for circuits used in electronic instrumentation. A variety of circuits that employ discrete components, operational amplifiers, I-C timers, and logic circuitry are considered. Emphasis is placed on designing for specified function rather than on detailed analyses. At the level of *The Art of Electronics*, by Horowitz and Hill.

435–436 Semiconductor Electronics I and II 435, fall; 436, spring. 4 credits each term. Prerequisites: Ele E 306 and 316.
3 lecs, 1 lab.
Basic physics of semiconductor materials, with emphasis on properties important for semiconductor devices; crystals, band structure, electron and hole transport, interfaces and contacts, optical properties related to junction diodes, bipolar and MOS transistors, lasers, and solar cells. In the second semester, the basic principles learned will be applied in the study of devices and technologies commonly used in integrated circuits. Computer modeling of devices.

442 Fundamentals of Acoustics (also T&AM 666) Spring. 3 credits.
3 lecs, biweekly lab.
See T&AM 666 for course description.

451–452 Electric Energy Systems I and II 451, fall; 452, spring. 4 credits each term. Prerequisite for 451: Ele E 316 or permission of instructor.
3 lec-recs, 1 lab-computing session. S. Linke.
Engineering principles underlying operation of modern electric-power systems under steady-state and transient conditions emphasizing major power-system parameters. Digital computer used as dynamic "laboratory" model of complex power systems for load-flow, fault, stability, and economic-dispatch studies. At the level of *Elements of Power System Analysis* (third ed.), by Stevenson.

455 Advanced Power Systems Analysis I Fall. 3 credits. Prerequisite: Ele E 302 and concurrent registration in 451, or permission of instructor.
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.

456 Advanced Power Systems Analysis II Spring. 3 credits. Prerequisites: Ele E 455 and concurrent registration in 452 or permission of instructor.
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.

475 Computer Structures Fall. 4 credits. Prerequisite: Ele E 230.
3 lecs, 1 lab. N. M. Vrana.
Organization and design of digital computers. Hardwired and microprogrammed control sequencers, arithmetic hardware, and I/O systems. Each four-to-six-person laboratory group will design and construct a small digital computer.

476 Microprocessor Systems Spring. 4 credits. Prerequisite: Ele E 475.
3 lecs, 1 lab. N. M. Vrana.
System design using microprocessors. Hardware and software techniques employed for logic design, interfacing, instrumentation, and control. The use of development systems.

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

481 Elementary Plasma Physics and Gas Discharges Fall. 3 credits. Prerequisite: Ele E 303 and 304 or equivalent.
2 lecs, 1 lab, field trips.

Principles and practices required to perform diagnostics of plasmas and intense particle beams. Coordinated lectures and ten experiments. Plasma breakdown, collisions, diffusion, sheaths. Reflex discharge. Discussion of macroscopic and microscopic measurements. Langmuir and other probes. Electromagnetic and spacecharge waves. Microwave and optical radiation. Intense particle beams. Methods for data collection and analysis.

484 Introduction to Controlled Fusion: Principles and Technology (also NS&E 484) Spring. 3 credits. Prerequisites: Ele E 301 and Ele E 303 or 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.

489 Magnetohydrodynamics Spring. 3 credits. Prerequisite: Ele E 581 or equivalent.
C. E. Seyler.
The theory of ideal and resistive magnetohydrodynamical equations with emphasis on application to controlled thermonuclear fusion. Topics: derivation and domain of applicability; invariants, waves and characteristics; static and stationary equilibrium; Grad-Shafranov equation; magnetic islands and 3-D equilibrium; linearized equations and normal-mode stability analysis; energy-principle and variational techniques; continuous spectrum; sharp-boundary model; cylindrical and toroidal confinement geometries; stability conditions; resistive effects. At the level of *MHD Instabilities*, by G. Bateman.

491–492 Senior Project 491, fall; 492, spring. 3 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.

521 Theory of Linear Systems Fall. 4 credits. Prerequisite: Ele E 302 or permission of instructor.
The state-space model for linear systems. Fundamental and transition matrices. Matrix exponential functions, the Cayley-Hamilton theorem, and the Jordan form. Forced network and system response. Controllability, observability, stability, realizability. Applications of Fourier, Laplace, Hilbert transforms. Paley-Wiener theorem. At the level of *System Theory*, by Padulo and Arbib.

531 Quantum Electronics I Fall. 4 credits. Prerequisites: Ele E 306 and 407 or Physics 443.
3 lecs, 1 rec-computing session.
A detailed treatment of the physical principles underlying lasers and masers, related fields, and applications. Topics include a review of quantum mechanics and the quantum theory of angular momentum; the interaction of radiation and matter, including emission, absorption, scattering and macroscopic material properties; theory of the laser, including methods of achieving total and partial population inversion; optical resonators; output power of amplifiers and oscillators; dispersive effects and laser oscillation spectrum.

532 Quantum Electronics II Spring. 4 credits. Prerequisite: Ele E 531 or permission of instructor.
3 lecs, 1 rec-computing session.
A continuation of Ele E 531. Topics include spectroscopy of atoms, molecules, and ions in crystals as examples of laser media; density matrix; nonlinear optics and optical processes; theory of coherence; integrated optics and optical communication.

533 Solid-State Microwave Devices and Circuits I Fall. 3 credits. Prerequisite: Ele E 304.
2 lecs, 1 lab.
Theoretical and experimental studies of circuits, amplifiers, oscillators, detectors, receivers, and electrical noise at microwave frequencies. Typical topics: one- and two-port resonators; negative resistance amplifiers; oscillator load characteristics, locking and stabilization; microwave transistor amplifiers; intermodulation effects; resistor and shot noise; noise temperature, FM noise.

534 Solid-State Microwave Devices and Circuits II Spring. 3 credits. Prerequisite: Ele E 533.
2 lecs, 1 lab.
Basic theories of solid-state devices at microwave frequencies. Specific devices studied: varactors, avalanche diodes; transferred electron diodes; pnp oscillator diodes; tunnel diodes; pin diodes; and microwave transistors. Studies of experimental methods of characterizing these devices include use of H.P. network analyzer and other microwave equipment.

536 Integrated Circuit Technology Spring. 4 credits. Prerequisite: Ele E 435 or permission of instructor.
2 lecs, 1 lab. P. Krusius.
Integrated-circuit fabrication techniques for solid-state circuits in the fields of computer hardware, telecommunication systems, and opto-electronics, with emphasis on processing, device design and logic-gate design. Lithography, crystal growth, diffusion, ion implantation, oxidation, chemical-vapour deposition, evaporation, sputtering, molecular beam epitaxy, etching, and in-process measurements. Silicon IC technologies with emphasis on bipolar and MOS devices and circuits. Standard processes, device and logic-gate design. Systems on chip. At the level of current papers in *IEEE Transactions on Electron Devices*.

561 Algebraic Coding Theory Fall. 3 credits. Prerequisites: probability and linear algebra.
An introduction to the theory of error-correcting linear block codes. Maximum likelihood decoding of linear block codes over discrete memoryless channels. Shannon's theorem for linear block codes over the binary symmetric channel. The Hamming sphere-packing, Singleton and Gilbert-Varshamov bound. Algebra: groups, rings, and fields, with special emphasis on Galois or finite fields. The construction and decoding of Bose-(Ray-) Chaudhuri-Hocquenghem (BCH) and Reed-Solomon (RS) codes, concatenated codes, burst error-correcting codes.

562 Fundamental Information Theory Spring. 3 or 4 credits (4 with lab). Prerequisite: Ele E 310 or equivalent. Prerequisite for lab only: Ele E 561 with lab.
3 lecs, 1 lab.
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. Lab projects investigate problems of statistical characterization of sources and channels using computer simulation.

564 Decision Making and Estimation Fall. 4 credits. Prerequisite: Ele E 310 or equivalent.
Utility theory and Bayes, minimax, and Neyman-Pearson decision theories. Bayes and maximum likelihood estimation. Cramer-Rao bound, Fisher information, efficient and consistent estimates. Applications drawn from the areas of pattern classification, detection, and communications.

567 Communication Systems I Fall. 4 credits. Prerequisite: Ele E 310 or equivalent.
2 lecs, 1 rec.
Analog and digital signal representation, spectral analysis, linear-signal processing, modulation and demodulation systems. Time and frequency division multiplex systems. Introduction to random processes and noise in analog and digital systems.

568 Communication Systems II Spring. 4 credits. Prerequisite: Ele E 567 or equivalent.
An introduction to digital communications. Discrete representations for signals: pulse-code modulation (PCM), delta modulation (DM), differential pulse-code modulation (DPCM), companding and Huffman coding. Digital modulator/demodulators (MODEMS): signal sets (e.g., phase shift keying (PSK), frequency shift keying (FSK), maximum a posteriori (MAP) and maximum likelihood (ML) receivers, probability of error, symbol timing and carrier tracking loops and intersymbol interference (ISI). Coded systems: convolutional codes, Viterbi and sequential decoding. Multiplexing: time division (TDM), frequency division (FDM), code division (CDM). Spread spectrum.

571 Feedback Control Systems Fall. 3 credits (4 with lab). Prerequisite: Ele E 302 or permission of instructor.
3 lecs, 1 lab. C. R. Johnson.
Analysis techniques, performance specifications, and analog-feedback-compensation methods for continuous-time systems. Design techniques include root-locus and frequency-response methods. Laplace transforms and transfer functions are the major mathematical tools. Laboratory work provides experience with measurement of systemic frequency-response, transient-response, and transfer function; design and compensation of linear-positional and speed-control systems; and computer-aided design techniques. Laboratory emphasis is on correlation of theoretical and experimental results.

572 Digital Control Systems Spring. 3 credits (4 with lab). Prerequisite: Ele E 571 or permission of instructor.
3 lecs, 1 lab. C. R. Johnson.
Analysis and design of feedback control systems using digital devices to implement compensation. Z-transforms, digital filtering equivalents, root-locus, frequency-response, PID, deadbeat, and state-variable techniques will be used. Quantization and sample-rate effects in sampled-data control systems will be considered. Laboratory work will consist of computer-aided design, digitally simulated evaluation, and microprocessor implementation. Laboratory emphasis is on practical process-control configurations.

573 Estimation and Control in Discrete Linear Systems Fall. 4 credits. Prerequisites: Ele E 302 and 310 or permission of instructor.
3 lecs.
Optimal control, filtering, and prediction for discrete-time linear systems with extensive use of the APL system. Approximation on discrete point sets. The principle of optimality. Kalman filtering. Stochastic optimal control.

574 Optimal Control and Estimation for Continuous Systems Spring. 4 credits. Prerequisite: Ele E 573 or permission of instructor.
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.

577 Computer Processor Organization and Memory Hierarchy Fall. 4 credits. Prerequisites: Ele E 476 and 310, or permission of instructor.
Design and evaluation of processor and memory architectures are examined in light of actual implementations of both large-scale and small-scale (microprocessor) systems. Topics include microprogramming and directly executable languages, number representation and instruction set trade-offs, parallel and pipelined architectures, interleaved memories, cache and virtual memories, multilevel memory hierarchies, and protection mechanisms.

578 Computer Networks and Distributed Architecture Spring. 4 credits. Prerequisite: Ele E 577 or permission of instructor.
Methods and approaches to input-output processing, parallel processing, task partitions and resource allocations, distributed processing, interconnection topology, minicomputer and microcomputer networks, interprocessor communications, protocols and performance evaluations.

579 Current Topics in Computer Engineering Fall. 3 credits. Prerequisite: Ele E 577 or coregistration in 577.
2 lecs.
In-depth treatment of current and emerging computer engineering research and development activities. Topics vary from year to year and are chosen from research reports and published journal articles. Subjects may include fault-tolerant computing, reliability studies, innovative microcomputer structures, direct execution of high-level languages, and impact of very-large-scale integration technologies on computer organizations.

581 Introduction to Plasma Physics (also A&EP 606) Fall. 4 credits. First-year graduate-level course; open also to *exceptional* fourth-year students at discretion of instructor. Prerequisites: Ele E 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.

582 Advanced Plasma Physics (also A&EP 607) Spring. 4 credits. Prerequisite: Ele E 581.
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.

583 Electrodynamics Fall. 4 credits. Prerequisite: Ele E 304 or equivalent.
3 lecs.
Maxwell's equations, electromagnetic potentials, integral representations of the electromagnetic field. Special theory of relativity. Radiation of accelerated charges. Cerenkov radiation. Optional topics: electrodynamics of dispersive dielectric and magnetic media; elementary quantum electrodynamics, second quantization, interaction of electromagnetic fields with atoms. At the level of *Classical Electrodynamics*, by Jackson, and *A Pedestrian Approach to Quantum Field Theory*, by Harris.

584 Microwave Theory Spring. 4 credits. Prerequisite: Ele E 304 or equivalent.
3 lecs. P. McIsaac.
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.

[**585–586 Upper Atmosphere Physics I and II** 585, fall; 586, spring. 3 credits each term. Not offered 1982–83.
3 lecs.
Physical processes in the earth's ionosphere and magnetosphere, the solar corona, and the solar wind. Diagnostic techniques including radar and *in situ* observations; production, loss, and transport of charged particles in the ionosphere and magnetosphere; airglow; tides, winds, and gravity waves; electric fields generated by the solar wind and winds in the neutral atmosphere, and their effects on transport processes; the equatorial and auroral electrojets; instabilities in space plasmas, structure of the solar corona and solar wind and their interaction with the magnetosphere; acceleration and drift of energetic particles in the magnetosphere; precipitation of particles and the aurora; magnetic and ionospheric storms.]

587 Electomagnetic Wave Propagation I Fall. 3 credits. Prerequisite: Ele E 304 or equivalent.
3 lecs.
Some aspects of antenna theory; diffraction; refraction and ducting in the troposphere; propagation of radiowaves and cold plasma waves in the ionosphere and magnetosphere; Alfven, whistler mode, and hybrid waves; the CMA diagram; WKB solutions of the coupled wave equations.

588 Electromagnetic Wave Propagation II Spring. 3 credits. Prerequisite: 587.
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; radio star and satellite scintillations and their use as diagnostic tools; radar astronomy.

591–599 Graduate Topics in Electrical Engineering 1–3 credits.
Seminar, reading course, or other special arrangement agreed upon between the students and faculty members concerned.

633 Opto-Electronic Devices Fall. 4 credits. Prerequisites: Ele E 304 and 435 or equivalent.
3 lecs, 1 rec.
An understanding of physical properties of solids that affect use in optical devices is sought. Wave propagation in lossy, anisotropic, layered, and electro-optic media; microscopic and band-theoretic models for dielectric constant and loss; carrier transport, scattering and trapping; photoconductivity; electro-optics, photoemissive and photoconductive devices; noise in optical detectors.

634 Theory and Applications of Nonlinear Optics 4 credits. Prerequisite: Ele E 531 or 633 or equivalent of Physics 572.
3 lecs, 1 rec.
Basic concepts and recent developments in nonlinear and electro-optics. Topics include higher-order perturbation theory of the Schroedinger and density-matrix equations and their applications in nonlinear optics; classical anharmonic oscillators; nonlinear optical properties of organic and inorganic crystals and semiconductors; harmonic generation and multiphoton processes; nonlinear and electro-optical devices and their applications in, for example, spectroscopy and optical communications. At the level of Rabin and Tang and current literature.

635 Solid-State Devices I Fall. 4 credits. Prerequisite: Ele E 436 or equivalent.
3 lecs.
Band structure, generation-recombination statistics, ambipolar transport, deep-level spectroscopy, p-n junction analysis, contact technology, secondary ionization, and noise. A review of ion-implantation technology with emphasis on associated material and device problems. Topics are presented on the level of current literature on device research. Presentation concentrates on relating basic material properties to device parameters. Term paper.

636 Solid-State Devices II Spring. 4 credits. Prerequisite: Ele E 635 or equivalent.
3 lecs.
A general treatment of the time dependence of secondary ionization and the simpler "quasistatic" approximation. Applications to microwave generation and amplification and broadband optical detection, including stability, nonlinearity, and noise. The fundamentals of transferred electron devices, including band structure, distribution functions, stability and doping configurations of devices.
Term paper.

638 Materials and Device Physics for VLSI 2–3 credits. Prerequisite: Ele E 436 or equivalent.
J. Frey.
Basic materials and device problems to be considered in the design and fabrication of VLSI circuits. High-field electron and hole transport; nonequilibrated electron transport; impact ionization; solutions of Boltzmann's equation using Monte Carlo techniques; role of velocity overshoot in short-channel devices, comparison of elemental and compound semiconductors. Submicron-scale phenomena in MOSFETs and bipolar devices; implications for circuit design.

639 VLSI Digital System Design Fall. 4 credits. Prerequisites: Ele E 436 and 476.
Theory of operation of MOS devices and circuits and their fabrication; the foundations of LSI system design and implementation; examples of LSI system design; and topics of current research relating to system timing, arrays of extensible LSI devices, algorithms consistent with VLSI processor arrays, and organization of hierarchical and concurrent computing devices. A laboratory project is required.

661–662 Random Processes in Electrical Systems 661, fall; 662, spring. 4 credits each term. Prerequisites: Ele E 302 and 310.
3 lecs.
The concepts of randomness and uncertainty and their relevance to the design and analysis of electrical systems. An axiomatic characterization of random events. Probability measures, random variables, and random vectors. Distribution functions and densities. Functions of random vectors. Expectation and measures of fluctuation. Moments and probability inequalities. Properties and applications of characteristic functions. Modes of convergence of sequences of random variables: laws of large numbers and central limit theorems. Kolmogorov consistency conditions for random processes. Poisson process and generalizations. Gaussian processes. Covariance stationary process, correlation function, spectra; Bochner and Wiener-Khinchin theorems. Continuity, integration, and differentiation of sample functions. Optimum filtering and prediction. Spectral representation, orthogonal series representations. Markov chains and processes. Linear and nonlinear transformations of random processes.

663 Advanced Topics in Information Theory Fall. 4 credits. Prerequisites: Ele E 562 and either 661 or Mathematics 571 or permission of instructor.
3 lecs.
An in-depth treatment of an information-theory research area. The topic varies from year to year and is chosen from the following subjects: source encoding (rate-distortion theory), decentralized systems, multiterminal communication networks, ergodic theory and information, complexity and instrumentability of coding schemes, coding for computer memory.

664 Foundations of Inference and Decision Making Spring. 3 credits. Prerequisite: a course in probability and some statistics, or permission of instructor.

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 comparative probability, quantitative probability, relative frequency interpretations, computational complexity, randomness, classical probability and invariance, induction, subjective probability.

673 Random Processes in Control Systems Spring. 4 credits. Prerequisites: Ele E 662 and 574.
Prediction and filtering in control systems: Gaussian-Markov process, prediction problem, stochastic optimal and adaptive control problems. Control of systems with uncertain statistical parameters; stochastic differential equations, optimal nonlinear filtering; stability of control systems with random parameters.

674 Adaptive Parameter Estimation Spring. 3 credits. Prerequisites: Ele E 426, 572, or permission of instructor.
Discrete prediction-error techniques of recursive parameter estimation. The course focuses on equation- and output-error formulations for parameter estimation in autoregressive, moving-average processes. Stability theory applicable to such nonlinear, time-varying systems is developed and used to analyze the convergence of various algorithms, including gradient-descent search, recursive least-squares, and recursive maximum-likelihood. These algorithms are applied to problems in adaptive filtering, identification, and control.

681 Kinetic Theory (also A&EP 761) Spring. 3 credits. Prerequisite: Ele E 407 or Physics 561, or permission of instructor. Offered alternate years.
2 lecs. R. L. Liboff.
Theory of the 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. Klimontovich formulation. At the level of *Introduction to the Theory of Kinetic Equations*, by Liboff.

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.

693–694 Electrical Engineering Design 693, fall; 694, spring. 3 credits each term. For students enrolled in the M.Eng.(Electrical) degree program.
Utilizes real engineering situations to present fundamentals of engineering design.

695–696 Graduate Topics in Electrical Engineering 1–3 credits.
Seminar, reading course, or other special arrangement agreed upon between 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 or spring. 3 credits.
2 lecs, 1 lab, field trips. Evening exams.
W. B. Travers, fall; A. L. Bloom, spring.
Understanding the natural earth; weathering, erosion, the evolution of coast lines and river valleys, glaciation, the origins of earthquakes and mountains, the genesis of volcanoes, and the drifting of continents. Studies of ground water, mineral deposits, petroleum, and coal. Recognizing major minerals and rocks, interpretation of topographic and geologic maps.

102 Introduction to Historical Geology Spring. 3 credits. Prerequisite: Geol 101 or permission of instructor.
2 lecs, 1 lab. Evening exams. J. L. Cisne.
A continuation of Geol 101. History of the earth and life in terms of evolutionary processes. The geologic record, its formation, and interpretation of earth history. Introduction to the evolution of life and to fossils and their use in reconstructing past environments and dating rocks.

[**103 Earth Science** Fall. 3 credits. See Geol 105, Earth Science Laboratory. Not offered 1982–83.
3 lecs. A. L. Bloom.
Physical geography, including earth and lunar orbits that determine seasons and tides. Figure and structure of the earth; climatic regions; atmospheric and oceanic circulation; erosion by rivers, glaciers, wind, and waves; climatic change.]

[**105 Earth Science Laboratory** Fall. 1 credit. To be taken concurrently with Geol 103, Earth Science. Not offered 1982–83.
A. L. Bloom.
Astronomical determination of position and seasonal events. Topographic mapping and map interpretation. Minerals and rocks, world climatic regions.]

107 Frontiers of Geology I Fall. 1 credit. May be taken concurrently with or after Geol 101.
1 lec. J. L. Cisne and staff.
Lectures by members of the department on selected fundamental topics of current interest, such as continental drift and related tectonic processes, volcanoes, earthquake prediction, natural energy sources, and mineral resources.

108 Frontiers of Geology II Spring. 1 credit. May be taken concurrently with or after Geo 101 or 102.
1 lec. J. L. Cisne and staff.
Lectures by members of the department on selected fundamental topics of current interest such as plate tectonics, the evolution of mountain belts and island arcs, the deep structure of continents, ecology and evolution of fossil organisms, correlation of strata by fossils, sea-level changes, and fossil fuels.

[**131 Geology and the Environment** Fall. 3 credits. Field trips. Not offered 1982–83.
2 lecs, 1 lab.
The principles of geological science, with emphasis on the physical phenomena and rock properties as they influence the natural environments of man.]

210 Introduction to Methods in Geological Sciences Fall. 2 credits. Prerequisite: Geol 101 or coregistration. Field trips.
Staff.
An introduction to the methods by which rocks are used as a geological data base. Students will be familiarized with such field methods as use of brunton compass, construction of geologic maps and sections from field data, and description of strata. Meetings will be held on Saturday mornings. All work will be done in the Ithaca area with the exception of one more-distant weekend field trip.

262 Mineral and Energy Resources and the Environment Spring. 3 credits. No prerequisites.
2 lecs, 1 lab. A. K. Gibbs.
A topical look at mineral and energy resource systems, their organization, and some of the physical, temporal, economic, and political constraints within which they operate. Not a survey course in geology or economics; instead, the focus is on a few exemplary problems and commodities.

Junior, Senior, and Graduate Courses

Of the following, the core courses Geological Sciences 325, 345, 355–356, 376, and 388 may be taken by those who have successfully completed Geological Sciences 101–102 or the equivalent, or who can demonstrate to the instructor that they have adequate preparation in mathematics, physics, chemistry, biology, or engineering.

325 Structural Geology and Sedimentation Spring. 4 credits. Prerequisite: Geol 101 or permission of instructor.
3 lecs, 1 lab. W. B. Travers.
Nature, origin, and recognition of geologic structures. Behavior of geologic materials. Geomechanical and tectonic principles applied to the solution of geologic problems. Introduction to the sedimentary processes and petrology of sedimentary rocks. Description, classification, provenance, transportation, depositional environment of sediments, and diagenesis of sediments.

345 Geomorphology Fall. 4 credits. Prerequisite: Geol 102 or permission of instructor.
2 lecs, 1 lab. A. L. Bloom.
Origin of land forms and description in terms of structure, process, and stage.

355 Mineralogy Fall. 4 credits. Prerequisite: Geol 101 or permission of the instructor.
2 lecs, 2 labs; assigned problems and readings. W. A. Bassett.
Examination of minerals by hand-specimen properties and optical microscopy. Geological setting, classification, crystal structures, phase relations, cheical properties, and physical properties of minerals are studied. X-ray diffraction is introduced.

356 Petrology and Geochemistry Spring. 4 credits.
2 lecs, 2 labs, 1 field trip; assigned problems and readings. J. M. Bird.
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.

376 Sedimentology and Stratigraphy Fall. 4 credits. Recommended: Geol 102.
2 lecs, 2 labs, field trips. S. Bachman.
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 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.

410 Experiments and Techniques in Earth Sciences Spring. 2 credits. Prerequisites: Physics 207–208 and Mathematics 191–192 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.

423 Petroleum Geology Fall. 3 credits. Recommended: Geol 325.
2 lecs, 1 lab. S. B. Bachman.

Introduction to hydrocarbon exploration and development. Source rock and fluid migration studies, oil and gas entrapment, reservoir rocks. Exploration techniques including basin analysis, subsurface mapping, seismic reflection methods and processing seismic mapping, seismic stratigraphy. Drilling techniques, well logs and their use in stratigraphic and structural interpretations, leasing and economics, career development.

[424 Tectonics of Orogenic Zones, Modern and Ancient Spring. 3 credits. Prerequisite; permission of instructors. Offered alternate years. Not offered 1982–83.
1 lec. D. E. Karig, W. B. Travers.
A comparative study of island arcs and mountain ranges.]

[428 Geomechanics Spring. 3 credits. Prerequisites: Mathematics 192, Geol 101. Not offered 1982–83.
3 lecs. D. L. Turcotte.
Use of mathematical analysis to explain such geological observations as ocean ridges—their thermal structure, elevation, heat flow, and gravity; ocean trenches—the structure and mechanics of the bending lithosphere; folding—buckling, viscous, and plastic flow; faulting—a detailed mechanical and geological study of the San Andreas fault; intrusives—geothermal power.]

[431 The Earth's Crust: Structure, Composition, and Evolution Fall. 3 credits. Prerequisites: Geol 356 and 388. Not offered 1982–83.
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 vs. continental crust. Origin and evolution of oceanic and continental crust.]

[432 Digital Processing and Analysis of Geophysical Data Spring. 3 credits. Prerequisites: Geol 488 and familiarity with a programming language. Not offered 1981–82.
3 lecs. L. D. Brown.
Sampling theory. Fourier, Laplace, and Z-transform techniques. Spectral analysis. Temporal and spatial filtering. Geophysical modeling. Deconvolution, migration, and velocity analysis of reflection data.]

433 Interpretation of Seismic Reflection Data Spring. 3 credits. Prerequisite: Geol 488 or equivalent.
2 lecs, 1 lab. L. D. Brown, S. Kaufman.
Techniques for inferring geologic structure and lithology from multichannel seismic reflection data. Data processing sequences, migration, velocity analysis, correlation criteria, resolution considerations, wave-form analysis, and synthetic seismograms. Synergistic approaches to interpretation. Seismic stratigraphy.

[454 Modern Petrology Fall. 3 credits. Prerequisite: Geol 356. Offered alternate years. Not offered 1982–83.
2½ lecs, ½ 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.]

[455 Isotope Geology Fall. 3 credits. Prerequisite: Geol 355–356 or equivalent. Not offered 1982–83.
3 lecs. R. W. Kay.
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 ^{14}C dating. Time constants for geochemical cycles. The use of O and H isotopes as tracers in the earth's hydrosphere, and hydrothermal circulation systems.]

456 Chemical Geology Spring. 3 credits. Prerequisite: Geol 355–356 or equivalent.
2 lecs, 1 lab. W. A. Bassett.
Crystallography and crystal chemistry of minerals and the methods of their study. Thermodynamic evaluation of homogeneous and heterogeneous equilibrium and disequilibrium processes of geologic interest. Topics include crystal symmetry, mineral structures, X-ray diffraction, mineral equilibrium, and difussion in minerals.

461 Mineral Deposits I Fall. 4 credits. Prerequisite: Geol 356 or permission of instructor.
3 lecs, 1 lab, field trip. A. K. Gibbs.
Introduction to mineral resources; sedimentary and magmatic deposits; topics in geochemistry; ore microscopy; and exploration methods.

462 Mineral Deposits II Spring. 4 credits. Prerequisite: Geol 461 or permission of instructor.
3 lecs, 1 lab, field trip. A. K. Gibbs.
Hydrothermal ore deposits; sulphide systems; related geochemical topics; mineral exploration.

[471 Invertebrate Paleontology and Biostratigraphy Fall. 4 credits. Prerequisite: Geol 102 and 376 or permission of instructor. Recommended prerequisite: some knowledge of biology. Not offered 1982–83.
2 lecs, 1 lab. J. L. Cisne.
Fossil invertebrates. Anatomy, classification, and identification of stratigraphically important groups. Applications of paleontology to geochronology and reconstruction of past environments.]

473 Sedimentation and Tectonics Spring. 3 credits. Prerequisite: Geol 376 or permission of instructor.
2 lecs, 1 disc. S. B. Bachman.
Interaction of sedimentation and tectonics in development of stratigraphic sequences. Framework of deep ocean, active margin, passive margin, and cratonic sedimentation and stratigraphy. Seismic stratigraphy and the effects of sea-level changes on the stratigraphic record; sedimentary petrology and tectonism. Examples of margin and cratonic development throughout the geologic record. Problems with applying plate tectonic models to very old rocks.

483 Marine Tectonics Fall. 3 credits. Prerequisites: Geol 325 and a course in physics or geophysics.
2 lecs, possible field trips. D. E. Karig.
Study of geophysical and geological characteristics of the earth's crust beneath the oceans. Review of strengths and limitations of marine exploratory techniques. Emphasis on recent geologic data concerning plate margins in the ocean, especially the island arc systems.

[485 Physics of the Earth I Fall. 3 credits. Limited to upperclass engineers, majors in the physical sciences, and others by permission of instructor. Not offered 1982–83.
2 lecs, 1 lab. D. L. Turcotte.
Rotation and figure of the earth, gravitational field, seismology, geomagnetism, creep and anelasticity, radioactivity, earth's internal heat, continental drift, and mantle convection.]

488 Introduction to Geophysical Prospecting Fall. 3 credits. Prerequisites: Physics 112 and 213 and Mathematics 191—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. Prerequisite: introduction to geology, physics, calculus, or permission of instructor. Offered alternate years.
B. L. Isacks.
The mechanism 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 Senior Thesis Fall or spring. 2 credits.
Staff.
Thesis proposal to be discussed with adviser during the junior year. Participation requires acceptance of a thesis proposal by the faculty committee.

610–639 Seminars and Special Work Fall and spring. 2 or 3 credits each term. Prerequisite: permission of instructor.
Advanced work on original investigations in geological sciences. Topics change from term to term.

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

611 Petrology and Geochemistry R. W. Kay.

612 Advanced Geomorphology Topics A. L. Bloom.

613 Marine Geology D. E. Karig.

614 Sedimentary Petrology and Tectonics S. B. Bachman.

615 Topics in Mineral Resource Studies and Precambrian Geology A. K. Gibbs.

616 Plate Tectonics and Geology J. M. Bird.

617 Paleobiology J. L. Cisne.

618 Geophysics, Exploration Seismology L. D. Brown.

619 Earthquakes and Tectonics B. L. Isacks.

620 Exploration Seismology, Gravity, Magnetics S.Kaufman.

621 Geophysics, Seismology, and Geotectonics J. Oliver.

622 Geomechanics, Gravity, Magnetism, Heat Flow D. L. Turcotte.

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

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

633 Advanced Topics in Petrology and Tectonics I J. Bird, W. Bassett.

634 Advanced Topics in Petrology and Tectonics II J. Bird, W. Bassett

635 Seminar in Tectonics D. Karig, S. Bachman.

637 Seminar in Petrology and Geochemistry R. Kay.

639 Seismic Record Reading B. Isacks.

642 Glacial and Quaternary Geology Spring. 3 credits. Prerequisite: Geol 345 or permission of instructor.
2 lecs, 1 lab; several Saturday field trips.
A. L. Bloom.
Glacial processes and deposits and the stratigraphy of the Quaternary.

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.

685 Advanced Geophysics I Fall. 3 credits. Prerequisite: Geol 388.
3 lecs. D. L. Turcotte.
Mantle convection, heat flow, the driving mechanism for plate tectonics, the energy balance, definition of the lithosphere.

686 Advanced Geophysics II Spring. 3 credits. Prerequisite: Geol 388.
3 lecs. D. L. Turcotte.
Gravity, figure of the earth, earth tides, magnetism, mechanical behavior of the lithosphere, changes in sea level.

[**687 Seismology I** Fall. 3 credits. Prerequisite: T&AM 611 or equivalent. Offered alternate years. Not offered 1982–83.
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.]

Field Courses

401 Field Geology Summer. 6 credits. Prerequisites: Geol 325 or permission of instructor. Six weeks at the Sierra Madre Field Camp, Wyoming. Fee, $1500.
W. B. Travers.
Field mapping techniques in igneous, metamorphic, and sedimentary rock, using topographic maps and air photos. The structural geology, petrology, geomorphology, and sedimentology of parts of Estes Park, Hanna Coal Basin, Wind River, and Beartooth Mountains will be studied. An independent project and report will be done during the last week. Sierra Madre field geology is a joint program of the Cornell, Yale, and Harvard departments of geological sciences.

[**601 Intersession Field Trip** January intersession. 1 credit. Prerequisites: Geol 101–102 or equivalent and permission of instructor. Travel and subsistence expenses to be announced. Not offered 1982–83.
A trip of one week to ten days in an area of interesting geology in the lower latitudes. Interested students should contact the instructor during the early part of the fall semester.]

604 Western Adirondack Field Course Spring, one week at the end of the semester. 1 credit. Students should be prepared for overnight camping and will have to pay for their own meals.
W. A. Bassett.
Field mapping methods, mineral and rock identification, examination of Precambrian metamorphic rocks and lower Paleozoic sediments, talc and zinc mines.

[**704 Western Field Course** Spring. 6 credits. Prerequisites: four courses in geological sciences at the 300 level, and permission of instructor. Students should be prepared for overnight camping and will have to pay for their own meals. Not offered 1982–83.
Weekly rec and 35-day trip to California, Nevada, and Utah. Staff.
A comparative study of California Coast Range, Sierra Nevada, Basin and Range of Nevada, and Uinta Mountains, Utah. Pretrip seminars and extensive reading at Cornell. Study of Mesozoic ophiolites, and subduction near San Luis Obispo, California; recent earth movements along the San Andreas fault near San Francisco; granitic pluton emplacement and volcanism in the northern Sierra Nevada; multiple-phase mountain building near Dixie Valley, Nevada; sedimentology and block faulting of the Uinta Mountains, Utah. Five-day raft trip on the Green River through the core of the Uinta mountains. Visit to an oil field in California and a mine in Nevada. Lectures and field trips with local experts.]

Materials Science and Engineering

Undergraduate Courses

201 Elements of Materials Science (also Engineering 111) Fall or spring. 3 credits.
Relations between atomic structure and macroscopic properties of such diverse materials as metals, ceramics, polymers. Properties discussed include magnetism, superconductivity, insulation, semiconductivity, mechanical strength, and plasticity. Applications to microelectronics, desalinization by reverse osmosis, superconducting power transmission lines, synthetic bones and joints, etc. Extensive use of slides, audiotutorial systems, movies.

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

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

331 Structural Characterization and Properties of Materials Fall. 4 credits.
3 lecs, 1 lab.
Crystal structures and crystal defects, stereographic methods. Binary-alloy structures, phase transitions, precipitation hardening, T-T-T diagrams in iron-carbon system. Structure and transitions of amorphous and partially ordered materials. Techniques for materials analysis: X-ray and electron diffraction, optical and electron microscopy. Implications for the design of materials with useful engineering properties.

332 Electrical and Magnetic Properties of Materials Spring. 3 credits.
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. Semiconductor devices and their optimized design. 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.
Semiindependent research project in association with faculty member and faculty research group of the department. Students design equipment and/or experiments and evaluate results. Creativity and synthesis are emphasized. Typical projects have involved hot isostatic compaction, sputter etching, mechanical testing of polymer films, and relation of properties to microstructure.

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. 3 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. Examples of design and control of materials processing and microstructure are discussed.

336 Kinetics, Diffusion, and Phase Transformations Spring. 3 credits.
3 lecs.
Introduction of absolute rate theory, atomic motion, and diffusion. Applications to nucleation and growth of new phases in vapors, liquids, and solids; solidification, crystal growth, oxidation and corrosion, radiation damage, recrystallization, gas-metal reactions, and thermo-mechanical processing to produce desired microstructures and properties.

345 Materials and Manufacturing Processes (also M&AE 311) Fall or spring. 3 credits. May be taken in addition to MS&E 261. Prerequisite: T&AM 202 or permission of instructor.
2 lecs, 1 lab.
See M&AE 311 for course description.

441 Microprocessing of Materials Fall. 3 credits.
3 lecs, occasional lab.
Introduction to engineering and design of large-scale integrated circuits. All the major processing steps involved in fabrication are considered. Metallurgical processes for winning high-purity silicon from SiO_2, single-crystal growth, zone melting and zone refining, Burton-Prim-Shlicter theory of the effective distribution coefficient, epitaxial growth of silicon. Thermal oxidation of silicon to form SiO_2, mathematical theory of solid-state diffusion with specific application to the doping of silicon to form integrated circuit devices, e.g., resistors, diodes, and bipolar transistors. Evaluation of diffused layers by electrical measurements. Linhard-Scharff-Schiott theory of ion implantation; stopping power, electronic and nuclear energy-loss mechanicms, range and damage profiles. Application of ion implantation to the fabrication of the MOSFET (metal-oxide-semiconductor-field-effect-transistor). Etching, metallization, photoresists, metal-semiconductor contacts, failure due to electromigration effects.

442 Macroprocessing. 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, etc. Emphasis is placed on 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.
3 lecs.
Relation between stress, strain, 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.

446 Current Topics in Materials Spring. 3 credits.
3 lecs.
Speakers from industry and other institutions will give case studies of design problems. Each student is expected to research, write an extensive term paper, and give a fifty-minute talk on a materials-design problem involving economic factors.

447 Introduction to Ceramics Fall. 3 credits. Prerequisite: MS&E 261 or permission of instructor. Offered alternate years.
3 lecs.
Engineering applications of ceramic materials and processes. Crystal structure and ionic bonding of ceramic materials; structure of glasses; point defects, point-defect chemistry and relation to nonstoichiometry; line defects and grain boundaries; diffusion in stoichiometric and nonstoichiometric oxides; phase diagrams; phase transformations and the design of glass-ceramics; grain growth and sintering.

448 Properties of Solid Polymers Spring. 3 credits.
3 lecs.
Synthetic and natural polymers for engineering applications. Production and characterization of long chain molecules. Gelation and networks, rubber elasticity, design of elastomers and thermosetting resins. Amorphous and crystalline thermoplastics and their structure. Time- and temperature-dependent elastic properties of polymers. Plastic deformation and fracture. Design of high-impact-strength polymers. Fiber drawing and fiber properties.

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

452 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 311.
3 recs.
See M&AE 512 for course description.

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.

Graduate-Level Professional Courses

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, including rubberlike behavior. At the level of *Physical Properties of Crystals*, by Nye.

603 Kinetics of Solid State Reactions Spring. 3 credits.
Elements of irreversible thermodynamics. General flux-force relationships. Material transport due to gradients in concentration, temperature, electrical potential, etc. Reaction-rate theory. Mechanisms of diffusion in solids and liquids. Role of defects. Transport at interfaces. Diffusion in alloys. Kinetics of phase transformation in solids. Mechanisms of oxidation. Crystal growth from vapor and liquid. Reactions produced by irradiation.

604 Structure of 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.

605 Plastic Flow and Fracture of Materials Fall. 3 credits.
Experimental and theoretical aspects of the deformation and failure of structural materials. Although the emphasis is on metals and alloys, consideration is given also to glasses, ceramics, and polymeric materials. Some of the topics included are theory and practice of mechanical testing, deformation behavior of polycrystal and single-crystal metals, phenomenological theories of deformation, micromechanical theories of plastic flow and creep, relationship of microstructure to mechanical properties, brittle and ductile fracture of materials.

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. Not offered 1982–83.
Introduction to diffraction phenomena as applied to solid-state problems. Scattering and adsorption of neutrons, electrons, and X-ray beams. Particular emphasis on synchrotron radiation X-ray sources. Fourier representation of scattering centers, and the effect of thermal vibrations. Phonon information from diffuse X-ray and neutron scattering and Bragg reflections. Diffraction from almost-periodic structures, surface layers, gases, and amorphous materials. Survey of dynamical diffraction from perfect and imperfect lattices.]

612 Phase Transformations 3 credits. Prerequisite: MS&E 601 and 603 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.

614 Electron Microscopy 3 credits.
Electron optics, Abbé theory of image formation with applications to the direct imaging of small defects and atomic planes. Kinematical theory of diffraction with applications to the study of the structure of grain boundaries and the imaging of crystal defects. Dynamical theory of diffraction as applied to the calculation of the images of crystal defects. Instruction in the use of the microscope.

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.

Specialty Courses

702 Amorphous and Semicrystalline Materials 3 credits. Prerequisite: Physics 454 or equivalent.
Topics related to the science of the amorphous state selected from within the following general areas: structure of liquids and polymers; rheology of elastomers and glasses; electrical, thermal, and optical properties of amorphous materials. Presented at the level of *Modern Aspects of the Vitreous State*, by Mackenzie; "Glass Transitions," by Shen and Eisenberg in *Progress in Solid State Chemistry;* and *The Physics of Rubber Elasticity*, by Treloar.

[703 Solid Surfaces and Interfaces 3 credits. Prerequisites: MS&E 601 and some knowledge of solid-state physics. Similar to A&EP 762. Offered alternate years.
Topics to be covered include atomic structure of surfaces, surface statistical thermodynamics, interaction of surfaces with gases, defects at surfaces, surfaces of alloys, semiconductor and insulator interfaces, heterogeneous catalysis, mass transport, oxidation of crystals.]

704 Advanced Topics in Crystal Defects 3 credits. Prerequisites: MS&E 601, 602, and 604, or equivalent.
The structure and properties of point, line, and planar crystal defects treated from a fundamental point of view. Thermodynamics and kinetics of point defects. Atomistic and continuum theories of dislocations. Thermodynamic treatment of grain boundaries.

Structure of grain boundaries. Emphasis given throughout to interactions between the various types of defects and to their roles in important phenomena such as diffusion, precipitation, plasticity, radiation damage.

705 The Effects of Radiation on Materials
3 credits.
Cross section for atom displacement; orientation dependence of the threshold energy; interatomic potentials; the atomic collision cascade; focusing of atomic collisions; mass transport along collision spectra within a cascade; range concepts and measurements in polycrystalline and single crystal metals and semiconductors; channeled particles and the effect of crystal imperfections on the range; Rutherford back-scattering and channeling and their application to the lattice location of impurity atoms; sputtering of single and polycrystalline metals; recovery mechanisms for radiation damage; void formation in metals irradiated to high fluences, and the problem of swelling in liquid-metal fast breeder reactors; the first-wall problem in controlled thermonuclear reactors. At the level of *Defects and Radiation Damage in Metals*, by M. W. Thompson; *The Observation of Atomic Collisions in Crystalline Solids*, by R. S. Nelson; *Ion Bombardment of Solids*, by G. Carter and J. S. Colligon; and selected papers and review articles.

706 Amorphous Semiconductors 2 credits. Prerequisite: knowledge of the theory of crystalline semiconductors on the level of Kittel.
The preparation, characterization, and the electronic transport of amorphous semiconductors from an experimental point of view. Particular emphasis is given to amorphous, hydrogenated Si. Some potential device applications, such as in amorphous Si solar cells and the metal-base transistor, are described.

707 Solar Energy Materials 3 credits.
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 JPL program to produce large quantities of solar-grade semiconducting Si.

708 Ceramic Materials 3 credits. Prerequisites: MS&E 601 and some familiarity with crystal structures.
Crystal structure and bonding of typical ceramic materials; structure of silicate and nonsilicate glasses; imperfections in oxides; point defects and point-defect chemistry, line defects, extended defects; diffusion in stoichiometric and nonstoichiometric ceramics; phase transformations; equilibrium and nonequilibrium phases; grain growth and sintering; plastic deformation and creep; topics from research papers.

775 Advanced Topics in Mechanical Properties
3 credits. Prerequisite: MS&E 605 or permission of instructor.
3 lecs.
Topics from current research in mechanical properties of structural materials, selected from the following: modern theories of deformation, high-strength alloys, effects of nuclear radiation, amorphous solids, cyclic deformation and fatigue, fracture of brittle and ductile solids, anelasticity and internal friction. Lectures are based largely on current literature.

779 Special Studies in Materials Sciences Fall or spring. Credit variable.
Supervised studies of special topics in materials science.

798 Materials Science and Engineering Colloquium Fall and 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 science, especially in connection with new research.

799 Materials Science Research Seminars Fall and 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 and 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 and 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.
R. L. Wehe.
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 Fall, spring. 1 credit. Half-term course offered twice each semester. Recommended for students without previous mechanical drawing experience. S-U grades optional.
2 lecs, 1 lab.
Practical demonstration of the relationship between engineering principles and the creative solution of real problems. Drawing and graphic techniques useful in design, analysis, and presentation of ideas. Computer graphics applied to problems of engineering design through use of CADIF (Computer-Aided Design Instructional Facility).

221 Thermodynamics (also Engineering 221) Fall, spring. 3 credits. Prerequisites: Mathematics 191 and 192, Physics 112. Evening prelims.
See description under Engineering Basic Studies.

302 Technology, Society, and the Human Condition Spring, summer. 3 credits. Approved liberal elective. Limited to upperclass engineers and other students who have received permission of instructor. S-U grades optional.
B. J. Conta.
An introduction to the history of technology from the origin of man to the present. Emphasis is on the social and human consequences of technology rather than on internal or gadget history. Of primary interest are the nineteenth and twentieth centuries and the pervasive effects of industrialization—a process that began with manufacturing and was rapidly extended to agriculture, culminating in what Ivan Illich has called the industrialization of man. Among the current topics included are the transition from an economy of abundance and affluence to one of impending shortages and limits to growth, alternative life styles, alternative energy sources and systems; and the growing interest in intermediate or appropriate technology.

311 Materials and Manufacturing Processes (also MS&E 345) Fall, spring; may be offered in Engineering Cooperative Program. May be taken in addition to Engr 261. Prerequisite: Engr 202 or permission of instructor. Evening prelims may be given.
2 lecs, 1 lab.
Material structures. Physical and metallurgical properties of materials and their control by mechanical and metallurgical means. Manufacturing processes. Emphasis on correlations among design, material properties, and processing methods.

323 Introductory Fluid Mechanics Fall, spring; usually offered in Engineering Cooperative Program. 4 credits. Prerequisites: Engr 202, 203 and 221, or permission of instructor.
4 recs. 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.

324 Heat Transfer Fall, spring; may be offered in Engineering Cooperative Program. Prerequisite: M&AE 323.
2 lecs, 1 rec. Evening prelims.
Conduction of heat in steady and unsteady situations. Fin surfaces 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. Multimode heat transfer. Diffusion mass transfer.

325 Mechanical Design and Analysis Fall, spring; usually offered in Engineering Cooperative Program. 4 credits. Prerequisites: Engr 202 and 203.
3 recs, 1 lab.
Application of the principles of mechanics and materials to problems of analysis and design of mechanical components and systems.

326 Systems Dynamics Fall, spring; may be offered in Engineering Cooperative Program.
4 credits. Prerequisite: M&AE 325. Evening prelims.
Dynamic behavior of mechanical systems, modeling, analysis techniques and applications, digital- and analog-computer simulation, balancing of rotating and reciprocating machinery, vibrations of single and multi-degree-of-freedom systems, linear control systems. PDF control, stability analysis.

327 Mechanical Engineering Laboratory Fall, spring. 4 credits. Prerequisites: M&AE 323, 325, and concurrent registration in M&AE 324 and 326.
1 lec, 2 labs.
Laboratory exercises in instrumentation, techniques, and methods in mechanical engineering. Measurements of pressure, temperature, heat flow, drag, fluid flow rate, solar energy, thermoelectricity, displacement, force, stress, strain, vibrations, noise.

Mechanical Systems and Design and Manufacturing

464 Design for Manufacture Fall. 3 credits. Prerequisites: M&AE 311 and 325, or permission of instructor.
Design for casting, forging, stamping, welding, machining, heat treatment, and assembly; beneficial prestressing; improving the distribution of loads and deflections. Selection of materials; dimensioning and fits; joints, fasteners, and shaft mountings. Specifications for manufacturing and maintenance to minimize fatigue failures and improve reliability. Short design problems.

483 Mechanical Reliability Fall. 3 credits. Prerequisites: Engr 260 or 270 or equivalent.
S. L. Phoenix.
Classic system reliability, hazard-function concepts, reliability bounds; static and time-dependent material-strength models, weakest-flaw models; structural system reliability, static and time-dependent

parallel-member models. Monte Carlo simulation of structural systems with load sharing. Strength of composite materials.

486 Automotive Engineering Spring. 3 credits. Prerequisite: M&AE 325.
Selected topics in the analysis and design of vehicle components and vehicle systems. Emphasis is on automobiles, trucks, and related vehicles. Powerplant, driveline, brakes, suspension, and structure. Other vehicle types may be considered.

489 Computer-Aided Design Spring. 3 credits. Limited to juniors and seniors.
2 lec-recs, 1 computing lab; term project.
A broad introduction to computational methods in mechanical design. Problems with emphasis on interaction techniques.

512 Analysis of Manufacturing Processes (also MS&E 455) Spring. 3 credits. Prerequisite: M&AE 311.
3 lecs.
Review of basic principles of plasticity with coverage of bound theorems and slipline theory. Analytical treatment of metal cutting and metal forming processes; conventional and nontraditional manufacturing methods; production systems and machine tool dynamics.

[**513 Materials Engineering** Spring. 3 credits. Prerequisite: M&AE 311, Engr 261, or permission of instructor. Not offered 1982–83.
Designed to aid in the design, selection, and use of engineering materials. Theory and practice of extractive, physical, and mechanical metallurgy. Corrosion principles and control; metallurgical failure analysis and prevention; mechanical properties of polymers, ceramics, and composite materials.]

514 Numerical Control in Manufacturing Fall. 3 credits. Prerequisite: upperclass standing in engineering.
3 lecs. K. K. Wang.
Principles and the state of the art of numerical control (NC) technology; programming methods for NC and computerized NC (CNC) machine tools with laboratories; economic aspects, and roles in computer-aided design/computer-aided manufacturing (CAD/CAM) systems with graphics.

563 Mechanical Components Spring. 3 credits. Prerequisite: M&AE 325.
Advanced analysis of machine components and structures. Application to the design of new configurations and devices. Selected topics from the following: lubrication theory and bearing design, fluid drives, shells, thick cylinders, rotating disks, fits, elastic-plastic design, thermal stresses, creep, impact, indeterminate and curved beams, plates, contact stresses.

565 Biomechanical Systems—Analysis and Design Spring. 3 credits. Prerequisites: Engr 202 and 203.
3 recs; term project. 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 orthopedic surgery and physical rehabilitation.

569 Mechanical and Aerospace Structures I Fall. 3 credits. Prerequisite: M&AE 325 or permission of instructor.
A study of advanced topics in the analysis of stress and deformation of deformable bodies, with applications to the analysis and design of mechanical and aerospace systems. Topics selected from advanced strength of materials, energy methods in stress analysis, strength theories, and experimental stress analysis.

570 Mechanical and Aerospace Structures II Spring. 4 credits. Prerequisite: M&AE 569 or permission of instructor.
Introduction to modern computational methods for elastic and thermal analysis of mechanical and aerospace structures. Emphasis on underlying mechanics and mathematics. Discussion of basic components and organization of typical general-purpose finite-element programs (e.g., NASTRAN). Selected engineering applications. Term project.

575 Microprocessor Applications Fall. 3 credits. Enrollment limited; intended for graduate students; open to qualified undergraduates who have permission of instructor. Prerequisite: background in basic laboratory electronics assumed.
Microprocessors for data acquisition and control; applications drawn from experiments and systems in mechanical engineering. Review of microcomputer systems, an introduction to digital circuitry, a survey of transducers and digital sensors. Basic concepts of digital control and detailed consideration of bus structure, data representation, interfacing, and input-output operations. Emphasis on single-chip and single-board microprocessors, with some extension to larger commercial systems. Independent laboratory work.

577 Mechanical Vibrations Spring. 3 credits. Open to qualified undergraduates. Prerequisite: M&AE 326 or equivalent.
2 recs, 1 lab.
Further development of vibration phenomena in single-degree- and multidegree-of-freedom linear and nonlinear systems, with emphasis on engineering problems involving analysis and design.

578 Feedback Control Systems Fall. 3 credits. Open to qualified undergraduates. Prerequisite: M&AE 326 or permission of instructor.
2 recs, 1 lab. R. M. Phelan.
Further development of the theory and implementation of feedback control systems, with particular emphasis on the application of pseudo-derivative-feedback (PDF) control concepts to the decision and operation of linear and nonlinear systems.

587 Dynamics of Vehicles Fall; offered on demand. 3 credits. Prerequisite: Engr 203.
Introduction to the dynamics of ground vehicles including cars, trucks, trailers, motorcycles, and railroad vehicles. Emphasis is on the handling behavior and stability of the automobile, tire theory, and suspension analysis. Performance and comfort criteria are developed. Further topics are included to reflect interests of the class.

616 Finite Element Methods in Thermo-mechanical Processes Fall. 4 credits. Prerequisites: introductory course work in finite-element methods and elasticity, or in analysis of manufacturing processes.
P. R. Dawson.
Application of finite-element methods in the analyses of mechanical deformation processes that are nonlinear and influenced by coupling to thermal or electrical behavior. Elastic, elastoplastic, viscoplastic, and thermally coupled analyses applied to problems in large deformation, bulk forming, polymer flows, and welding.

[**672 Experimental Methods in Machine Design** Fall. 4 credits. Prerequisite: M&AE 325 or equivalent. Not offered 1982–83.
1 rec, 2 labs.
Investigation and evaluation of methods used to obtain design and performance data. Photoelasticity, strain measurement, photography, vibration and sound measurements, transducers.]

[**676 Advanced Mechanical Vibrations** Fall. 4 credits. Prerequisite: M&AE 577 or equivalent. Offered alternate years. Not offered 1982–83.
D. L. Taylor.
Vibratory response of multidegree-of-freedom systems, matrix formulation, concepts of impedance, mobility, frequency response, and complex mode shapes. State-of-the-art techniques such as FFT, sine sweep, and single-point random excitation. Nonlinear vibrations, limit-cycle analysis, parametric resonance, self-excited oscillations, and nonconservative systems. Random vibrations and stochastic excitation. Introduction to vibrations of elastic bodies.]

[**679 Digital Simulation of Dynamic Systems** Fall. 4 credits. Open to qualified undergraduates who have permission of instructor. Prerequisite: previous exposure to systems dynamics and digital programming. Offered alternate years. Not offered 1982–83.
J. F. Booker.
Modeling and representation of physical systems by systems of ordinary differential equations in state vector form. Applications from diverse fields. Simulation diagrams. Analog and digital simulation by direct integration. Problem-oriented digital-simulation languages (e.g., CSMP). Digital analysis of stability and response of large linear systems.]

682 Hydrodynamic Lubrication: Fluid-Film Bearings Fall; offered on demand. 4 credits.
J. F. Booker.
Designed to acquaint those having a general knowledge of solid and fluid mechanics with the special problems and literature currently of interest in various fields of hydrodynamic lubrication. General topics include equations of viscous flow in thin films, self-acting and externally pressurized bearings with liquid and gas lubricant firms, bearing-system dynamics, and computational methods. Also selected special topics, such as elastohydrodynamic lubrication.

[**684 Advanced Mechanical Reliability** Fall. 4 credits. Prerequisite: M&AE 483 or permission of instructor. Offered alternate years. Not offered 1982–83.
S. L. Phoenix.
Advanced course in random loading and statistical failure processes in mechanical systems. Continuous and discrete random loadings, random vibrations of mechanical structures, random fatigue processes in materials, order statistics and statistical estimation of reliability, simulation, and computation in mechanical structures, coherent systems and monotone load-sharing, stochastic failure of bundles and composites.]

685 Optimum Design of Mechanical Systems Spring. 4 credits. Prerequisite: graduate standing or permission of instructor.
3 recs. 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.

Energy, Fluids, and Aerospace Engineering

405 Introduction to Aeronautics Fall. 3 credits. Limited to upperclass engineers or other students who have received 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.
A. R. George.

Hearing, music, noise, and noise-control criteria. Sound propagation, transmission, and absorption. Sound radiation by surfaces and flow. Loudspeakers. Room acoustics and noise-control techniques.

449 Combustion Engines Fall. 3 credits. Prerequisite: Engr 221 and concurrent registration in M&AE 323.
Evening prelims.
Introduction to combustion engines with emphasis on application of thermodynamics and fluid dynamics. Air-standard analyses, chemical equilibrium, ideal-cycle analyses, deviations from ideal processes. Fuels. Combustion knock. Carburetics. Fuel injection. Formation and control of undesirable exhaust emissions.

[**459 Plasma Energy Systems** Spring; offered on demand. 3 credits. Prerequisite: Physics 214, undergraduate or graduate standing in engineering. Not offered 1982–83.
Fundamental aspects of plasma physics. An elementary treatment of principles on which the concepts of controlled thermonuclear (fusion) reactors are based. Comparisons between fission and fusion systems and treatment of other plasma devices (e.g., MHD converters) as time permits.]

506 Aerospace Propulsion Systems Spring. 3 credits. Prerequisite: M&AE 323 or permission of instructor. Offered alternate years.
3 lecs.
Application of thermodynamics and fluid mechanics to design and performance of thermal-jet and rocket engines. Mission analysis in space. Auxiliary power supply; study of advanced methods of space propulsion.

507 Dynamics of Flight Vehicles Spring. 3 credits. Prerequisites: M&AE 405 and Engr 203 or permission of instructor. Offered alternate years.
D. A. Caughey.
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. Prerequisite: M&AE 323; senior or graduate standing, or permission of instructor.
Inviscid fluid dynamics and aerodynamics, including incompressible and supersonic flows, flow over bodies, lift, and drag. One-dimensional steady and unsteady compressible flows. Shock waves, wave drag, flow in jet and rocket engines. 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. Prerequisite: M&AE 323; senior or graduate standing, or permission of instructor. Recommended: M&AE 530 or equivalent.
Navier-Stokes equations for laminar and turbulent flows. Boundary layers, laminar and turbulent; skin friction, separation and transition. Jets and wakes, if time allows.

536 Turbomachinery and Applications Spring. 3 credits. Prerequisite: M&AE 323 or equivalent.
3 lecs.
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, 324.
3 recs.
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. Both premixed and diffusion flames are considered.

554 Solar Energy Fall. 3 credits. Prerequisite: Engr 221 or equivalent.
B. J. Conta.
Fundamentals of solar radiation. Direct solar radiation as a source of heat and electrical energy. The indirect uses of solar radiation; water, wind, and biomass. Applications to architecture and environment control by both active and passive means. Industrial uses of solar energy and the production of liquid and gaseous fuels. Economics and systems analysis.

555 Direct Energy Conversion and Storage Spring. 3 credits. Prerequisite: Engr 221 or equivalent. Offered alternate years.
3 lecs.
Primarily a survey of methods for the direct conversion of heat into electrical energy, with emphasis on efficiency, maximum power, practical applications, and limitations. Thermoelectric generators and refrigerators. Thermionic generators. Solar cells. Batteries. Fuel cells.

556 Power Systems Fall. 3 credits. Prerequisite: M&AE 323 or equivalent.
F. K. Moore.
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.

557 Future Energy Systems Seminar Spring. 3 credits. Prerequisite: an energy-related course. Options for future energy-conversion systems or power generation, transportation, and other end-use applications. Technical feasibilities, benefits, and environmental impacts are considered. Classes or seminars based on study projects that reflect student preparation and interests, conducted with faculty advice.

559 Introduction to Controlled Fusion: Principles and Technology (also 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. 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.

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 description of fluid flow, tensor analysis, derivation of the Navier-Stokes equations for compressible fluids. Vorticity dynamics. Inviscid limits of the equations of motion. Shock and contact discontinuities, conservation laws. Laminar and turbulent flows.

602 Incompressible Aerodynamics Spring. 4 credits. Prerequisite: M&AE 601 or equivalent. Open to qualified undergraduates with permission of instructor.
Basic equations for inviscid fluid motion. Vorticity and general Biot-Savart law. Irrotational flows and consequences of Green's theorem. Solution methods based on singularities. Complex variable technique for two-dimensional flows. Airfoil, wing, and slender-body theories. Unsteady phenomena.

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. Shock waves, method of characteristics, wave interactions. Perturbation theories and similarity rules. Linearized supersonic flow, wing theory, wave drag. Nonlinear theory of supersonic flow.

608 Physics of Fluids I Fall. 4 credits. Kinetic theory of gases: transport properties; derivation of the macroscopic equations of mass, momentum, and energy; flow of rarefied gases. Statistical mechanics of gases: method of the most probable value, Darwin-Fowler method of mean values, law of mass action.
Introduction to wave mechanics: harmonic oscillation, rigid rotator, one-electron atom. Atomic and molecular structure: building-up principle, Born-Oppenheimer approximation. Chemical reaction rate theory.

609 Physics of Fluids II Spring, on demand. 4 credits.
Molecular structure bonding theory, heats of reaction. Atomic and molecular spectroscopy, applications to pollution. Nonequilibrium statistical mechanics; Boltzmann equation, H-theorem, review of Hilbert-Enskog- Chapman theory, fluctuations. Onsager's relations. Radiative transfer, lasers. At the level of *The Dynamics of Real Gases,* by Clarke and McChesney.

610 Gasdynamics Spring. 4 credits. Offered on demand.
E. L. Resler, Jr.
A survey of the nonlinear theory of characteristics as applied to two-dimensional steady supersonic flows and one-dimensional unsteady flows. The role of chemical reactions in these flows is treated, as well as experimental techniques to measure chemical reaction rates. Among the topics treated are heat-capacity lag and its effects on acoustics, gasdynamic lasers, and shock-tube techniques. Magneto-acoustics and magnetically driven shock waves are also covered.

630 Atmospheric Turbulence and Micrometeorology Spring. 4 credits. Offered alternate years. 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.

[**648 Seminar on Combustion** Spring. 4 credits. Prerequisite: permission of instructor. Offered alternate years. Not offered 1982–83.
3 recs.
Discussion of contemporary problems in combustion research with emphasis on applications of modern experimental and analytical techniques. Typical problems include formation and removal of pollutants in combustion systems, combustion of alternative fuels, coal combustion, and modification of combustion systems for energy-efficiency improvement.]

650 Transport Processes I Fall. 4 credits. Prerequisite: graduate standing or permission of instructor.
Advanced treatment of heat conduction and thermal radiation. Differential and integral conduction equations. Exact and approximate solutions; superposition; phase-change boundaries. Radiative transport equation and Kirchhoff's laws. Emission and scattering by real surfaces and by gases. Heat exchange in enclosures.

651 Transport Processes II Spring. 4 credits. Prerequisite: graduate standing or permission of instructor.
Advanced convection heat transfer. Integral and differential formulations. Basic equations reasoned in detail. Exact and approximate solutions. Forced convection. Natural convection. Laminar and turbulent flows. Effects of viscous dissipation and mass transfer.

652 Boiling and Two-Phase Flow Fall. 4 credits. On demand. 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. Convective boiling and condensation. Industrial applications.

653 Experimental Methods in Fluid Mechanics, Heat Transfer, and Combustion Fall. 4 credits
2 lecs, 1 lab. F. C. Gouldin.
Study of experimental techniques for measuring pressure, temperature, velocity, and composition of gases, with emphasis on experimental capabilities and principles underlying the techniques. Topics include laser velocimetry, hot-wire anemometry, and spectroscopy.

704 Viscous Flows Spring; offered on demand. 4 credits. Prerequisite: M&AE 601 or permission of instructor.
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.

707 Aerodynamic Noise Theory Offered on demand. 4 credits. Prerequisites: M&AE 601 or permission of instructor.
Advanced topics in acoustics relevant to aerodynamic and transportation noise sources and control. Random processes. Geometrical acoustics in inhomogeneous moving media, Kirchhoff and Poisson formulas, diffraction, scattering. Lighthill-Curle formulations for sound generation. Absorption and transmission in fluids and at boundaries. Applications to aerodynamic noise sources.

733 Stability of Fluid Flow On demand. 4 credits. Prerequisite: Graduate standing or permission of instructor.
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 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.

735 Dynamics of Rotating Fluids Offered on demand. 4 credits. Prerequisites: M&AE 601 or permission of instructor.
S. Leibovich.
Review of classical fluid mechanics. Rotating coordinate systems. Linearized theory for rapidly rotating fluids. Inviscid regions, viscous layers. Spinup. Motions past objects. Waves in rotating fluids. Motions in concentrated vortices. Vortex breakdown in swirling flows. Boundary-layer Interactions.

737 Numerical Methods in Fluid Flow and Heat Transfer Spring. 4 credits. Prerequisites: graduate standing and some FORTRAN programming experience.
K. E. Torrance.
Discretization procedures for the Navier-Stokes and scalar transport equations. Finite differences and finite elements. Analysis of accuracy, stability, and convergence. Survey and comparison of current methods with applications. Assigned problems are solved with a digital computer.

738 Nonlinear Wave Propagation Offered on demand. 4 credits. Prerequisite: M&AE 601 or permission of instructor.
S. Leibovich.
Mathematical treatment of nonlinear effects associated with waves in continua. Examples are taken primarily from geophysical fluid dynamics and gas dynamics. Methods of averaging, variational methods, wave interactions, and exact solutions of nonlinear evolution equations.

Special Offerings

393 Current Topics in Biomechanics Fall or spring. 0 or 1 credit. May be taken twice for credit. Students who register for credit are required to submit summaries of lectures. S-U grades only.
D. L. Bartel
Weekly lecture series open to students and community at large: lectures on a common topic; reports of current research and design projects at Cornell; career and study opportunities. Lectures by Cornell faculty, graduate students, and visiting scientists.

490 Special Investigations in Mechanical and Aerospace Engineering Fall or 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.

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.

592 Seminar and Design Project in Aerospace Engineering Fall and spring. 2 credits each term. Intended for students in M.Eng.(Aerospace) program.
Study and discussion of topics of current research interest in aerospace engineering. Individual design projects.

690 Special Investigation in Mechanical and Aerospace Engineering Fall or spring. Credit to be arranged. Limited to graduate students.

695 Special Topics in Mechanical and Aerospace Engineering Fall or spring. Credit arranged. Prerequisite: permission of instructor.
Lecture or seminar format.
Topics of current importance in mechanical and aerospace engineering and research. More than one topic may be taken if offered.

791 Mechanical and Aerospace Engineering Research Conference Fall and spring. 1 credit each term.
For graduate students involved in research projects. Short presentations on research in progress by students and staff.

799 Mechanical and Aerospace Engineering Colloquium Fall and spring. 1 credit each term. Credit limited to graduate students. All students and staff invited to attend.
Lectures by Cornell staff members, graduate students, and visiting scientists on topics of 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 the director. Independent research in an area of mechanical and aerospace engineering under the guidance of a member of the staff.

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 staff.

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, 613, 633, 634, 636, 638, 651, and 652.

303 Introduction to Nuclear Science and Engineering I (also A&EP 303) Fall. 3 credits. Prerequisite: Physics 214 or Mathematics 294. This course and NS&E 304 and 305 form a coordinated, two-term sequence 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. The sequence can also serve as a basic course for those who do not intend to continue in the field. 303 is a reasonably self-contained unit that can be taken by itself by those desiring only one term.
3 lecs. D. A. Hammer.
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.

304 Introduction to Nuclear Science and Engineering II (also A&EP 304) Spring. 3 credits. Prerequisite: NS&E 303.
3 lecs. D. D. Clark.

Introduction to aspects of nuclear reactor engineering and to controlled fusion. Topics include heat-transfer and safety problems in fission reactors; principles, configurations, and engineering problems of proposed fusion reactors; radiation detection, shielding, biological effects of radiation, and materials damage.

305 Introduction to Nuclear Science and Engineering III Spring. 1 credit. Prerequisite: NS&E 303.
1 lec. D. D. Clark.
A one-hour reading and lecture course providing a more extensive development of the topics in nuclear physics introduced in NS&E 303. Recommended as a supplement to 303–304 for students who plan graduate work in nuclear science or engineering.

484 Introduction to Controlled Fusion: Principles and Technology (also Electrical Engineering 484 and M&AE 559) Spring. 3 credits. Prerequisites: Phys 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. 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.

605 Interaction of Radiation and Matter Spring. 4 credits. Prerequisite: a course in modern physics including quantum mechanics.
3 lecs. V. O. Kostroun.
Quantization of the electromagnetic field; relativistic wave equation of the electron; electrons interacting with radiation field—emission, absorption, dispersion, photoelectric effect. Compton scattering, scattering of two electrons, bremsstrahlung, pair production, and annihilation; passage of heavy charged and neutral particles through matter. Examples and applications from low-energy nuclear, plasma, and solid-state physics.

Operations Research and Industrial Engineering

260 Introductory Engineering Probability (also Engineering 260) Fall or spring. 3 credits. Prerequisite: first-year calculus.
3 lecs.
See description under Engineering Common Courses.

270 Basic Engineering Probability and Statistics Fall or spring. 3 credits. Prerequisite: first-year calculus.
3 lecs.
See description under Engineering Common Courses.

320 Optimization I Fall. 4 credits. Prerequisite: Mathematics 293 or 221.
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. The computer is used in solving typical problems.

350 Cost Accounting, Analysis, and Control Fall or spring. 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 on 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 or spring. 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; curve fitting.

410 Industrial Systems Analysis Spring. 4 credits. Prerequisites: OR&IE 350 and 370.
3 lecs, 1 computing session.
Engineering economic analysis, including engineering economy, replacement, taxation effects, decision making based on economic considerations. Operations analysis including process flow, process evaluation, procedural analysis, resource layout, methods analysis and design, work measurement, job evaluation, quality control elements. Project planning and control.

417 Layout and Material Handling Systems Spring. 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.
Planning and control of large-scale production operations. Inventory control. Leveling, smoothing, and scheduling of production. Job-shop scheduling and dispatching. Demand forecasting. Economic and practical interpretation of planning and control procedures.

431 Discrete Models Spring. 3 credits. Prerequisite: OR&IE 320 or permission of instructor.
3 lec-recs.
Basic concepts of graphs, networks, and discrete optimization. The use of finite mathematical techniques to model contemporary problems selected from operations research, including voting procedures and decision making, efficient and equitable allocations, energy and environment, traffic and urban systems.

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. Structure theory for games arising from complex organizations.

[**462 Introductory Engineering Stochastic Processes II** Fall. 4 credits. Not offered 1982–83. 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.]

471 Applications of Statistics to Engineering Problems Fall. 4 credits. Prerequisite: OR&IE 370 or equivalent.
3 lecs, 1 rec.
Sample size calculations for one- and two-sample tests; theory of multiple linear regression and applications to problems in engineering and the sciences, including graphic and analytic techniques useful in model building; analysis of data from experiments with qualitative factors including one-way and two-way Anova models. Use of the computer as a tool for statistics is stressed.

[**472 Statistical Decision Theory** Spring. 3 credits. Prerequisite: OR&IE 471 or equivalent. Not offered 1982–83.
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.]

516 Mathematical Models—Development and Application Fall. 4 credits. Prerequisites: OR&IE 320 and 361 or permission of instructor.
4 rec-labs.
A laboratory course concerned with structuring problems and operational systems as mathematical models. A sequence of situations for which students must construct representative models is considered. Models are examined for their usefulness in analysis, synthesis, and design.

519 OR&IE Project Fall or spring. Credit to be arranged. Prerequisite: permission of instructor.
Project-type work, under faculty supervision, on a real problem existing within some firm or institution, usually a regional organization. Opportunities in the course may be discussed with the associate director.

551 Advanced Engineering Economic Analysis Spring. 4 credits. Prerequisites: OR&IE 350 and knowledge of linear programming and statistics, or permission of instructor.
3 lecs, 1 rec.
The economics of production. Topics concerning economic decision making at the level of the firm include long-range planning, budgeting and control, and project investment decisions under certainty and uncertainty. Topics in industrial economics include productivity, technical change, and industrial development.

561 Queueing Theory and Its Applications Fall. 3 credits. Prerequisite: OR&IE 361 or permission of instructor.
3 lecs.
Basic queueing models. Design and control of queueing systems. Statistical inference from queueing processes. Solution techniques (including simulation). Scheduling and equipment maintenance. Highway and urban traffic networks. Analysis of computer systems.

562 Inventory Theory Spring. 4 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-term and single-location problems. Multi-item and multi-echelon extensions. Dynamic and static models are discussed. Redistribution methods are analyzed. Applications are stressed.

563 Applied Time Series Analysis Spring. 3 credits. Prerequisite: OR&IE 361, Com S 211, or permission of instructor.
2 lecs, 1 rec; final project.
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. Long-range dependence models and the related statistics are considered. As time permits, other topics such as spectral analysis, filtering, the sampling and aliasing problem, and the fast Fourier transform algorithm are discussed. Applications to economics and hydrology are emphasized. Assignments require computer work.

[570 Statistical Methods in Quality and Reliability Control Spring. 3 credits. Prerequisite: OR&IE 370 or equivalent. Not offered 1982–83.
3 lecs.
Control concepts and methods for attributes and variables; process capability analysis; acceptance sampling plans; elementary procedures for variables; acceptance-rectification procedures. Reliability concepts; exponential and normal distributions in reliability; life and reliability analysis of components and systems; redundancy.]

580 Digital Systems Simulation Fall. 4 credits. Prerequisites: Com S 211 and OR&IE 370 or permission of instructor.
2 lecs, 1 rec.
Digital computer programs to simulate the operation of complex discrete systems in time. Modeling, program organization, random number and deviate generation, simulation languages, statistical considerations; applications to a variety of problem areas.

599 Project Fall and spring. 5 credits. For M.Eng. students.
Identification, analysis, design, and evaluation of feasible solutions to some applied problem within the OR&IE field. A formal report and oral defense of the approach and solution are required.

[614 Facilities Location and Design Spring. 3 credits. Prerequisite: OR&IE 320 or 622 or permission of instructor. Not offered 1982–83.
3 lec-recs.
Formulation, analysis, and solution techniques for location and facility design problems. Applications in industrial environmental and regional areas.]

622 Operations Research I Fall. 3 credits. Not open to students who have had OR&IE 320.
3 lec-recs.
Survey of deterministic models. Models are drawn from linear, mixed-integer, nonlinear, and dynamic programming. Network theory, game theory, and deterministic inventory models. Modeling and applications are stressed.

623 Operations Research II Spring. 3 credits. Not open to students who have had OR&IE 361. Prerequisite: OR&IE 260 or 270 or permission of instructor.
3 lec-recs.
Models of inventory and production control. Markov decision models, queueing theory and its applications. Simulation. Illustrative examples and problems.

[625 Scheduling Theory Fall. 3 credits. Prerequisite: permission of instructor. Not offered 1982–83.
3 lec-recs.
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.]

[626 Advanced Production and Inventory Planning Spring. 3 credits. Not offered 1982–83.
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.]

630–631 Mathematical Programming I and II 630, fall; 631, spring. 3 credits each term. Prerequisite: advanced calculus.
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. 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 1982–83.
3 lecs.
Necessary and sufficient conditions for unconstrained and constrained optima. Computational methods, including interior (e.g., penalty functions), boundary (e.g., gradient projection), and exterior (e.g., cutting plane) approaches.]

635 Game Theory I Fall. 3 credits. Prerequisite: Mathematics 411 or permission of instructor.
3 lecs.
The minimax theorem for two-person zero-sum games. Two-person general sum games and noncooperative n-person games; Nash equilibrium points. Cooperative n-person games; the core, stable sets, Shapley value, bargaining set, kernel, nucleolus.

637 Dynamic Programming Spring. 3 credits. Prerequisite: concurrent registration in OR&IE 660 and Mathematics 411 or equivalent.
3 lecs.
Optimization of sequential decision processes. Deterministic and stochastic models, infinite horizon Markov decison models, policy iterations. Contraction mapping methods. Applications drawn from inventory theory, production control; discrete combination examples.

639 Convex Analysis Fall. 3 credits. Prerequisite: Mathematics 411 and 431 or permission of instructor.
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.

[641 Integer Programming Spring. 3 credits. Prerequisite: OR&IE 630. Not offered 1982–83.
3 lecs.
Discrete optimization. Linear programming in which the variables are restricted to be integer-valued. Theory, algorithms, and applications. Cutting plane methods, enumerative methods, and group theoretic methods; additional topics are drawn from recent research in this area.]

643 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.

644 Combinatorial Optimization Spring. 3 credits. Prerequisite: permission of instructor.
3 lecs.
Topics in combinatorics, graphs, and networks. These include matching, matroids, polyhedral combinatorics, and optimization algorithms.

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. 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.

662 Advanced Stochastic Processes Fall. 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, stochastic calculus, weak convergence.

[665 Advanced Queueing Theory Fall. 3 credits. Prerequisite: OR&IE 660 or equivalent. Not offered 1982–83.
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 Applied Statistics 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.

671 Intermediate Applied Statistics Fall. 4 credits. Prerequisite: OR&IE 670 or equivalent.
3 lecs, 1 rec.
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. Correlation, ridge regression. Use of the computer as a tool for statistics is stressed.

672 Statistical Decision Theory Fall. 3 credits. Prerequisite: OR&IE 471 or 670 or equivalent.
3 lecs.
The general problem of statistical decision theory and its applications. Comparison of decision rules; Bayes, admissible, and minimax rules. Problems involving sequences of decisions over time. Use of the sample cdf and other simple nonparametric methods. Applications.

[673 Nonparametric Statistical Analysis Spring. 3 credits. Prerequisite: OR&IE 670 or permission of instructor. Not offered 1982–83.
3 lecs.
Estimation of quantiles, cdf's and pdf's. Properties of order statistics and rank-order statistics. Hypothesis testing in one- and several-sample situations; sign

tests; use of ranks for tests and estimation. Small and large sample properties of tests. Asymptotic distributions of test statistics. Testing goodness of fit.]

674 Design of Experiments Spring. 4 credits. Prerequisite: OR&IE 671 or permission of instructor.
3 lecs.
Use and analysis of experimental designs such as randomized blocks and Latin squares; analysis of variance and covariance, factorial experiments; statistical problems associated with finding best operating conditions; response-surface analysis.

675 Qualitative Data Analysis Spring. 3 credits. Prerequisite: OR&IE 671.
Varieties of categorical data; cross classifications and contingency tables; tests for independence; multidimensional tables and log-linear models; maximum likelihood and weighted least squares estimation; tests of goodness of fit; analysis of incomplete tables; life tables; paired comparison experiments.

[676 Statistical Analysis of Life Data Fall. 3 credits. Prerequisite: OR&IE 671 or equivalent. Not offered 1982–83.
Analysis of data from reliability, fatigue, and life-testing studies in engineering; also 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.]

729 Selected Topics in Applied Operations Research Fall or spring. Credit to be arranged.
Current research topics dealing with applications of operations research.

[736 Game Theory II Spring. 3 credits. Prerequisite: OR&IE 635. Not offered 1982–83.
3 lecs.
A continuation of OR&IE 635, including in-depth treatment of some of the same topics plus such additional topics as games in extensive form, games without side payments, economic market games, and games with infinitely many players.]

738 Selected Topics in Game Theory Fall or spring. Credit to be arranged.
Current research topics in game theory.

739 Selected Topics in Mathematical Programming Fall or spring. Credit to be arranged.
Current research topics in mathematical programming.

[752 Advanced Inventory Control Spring. 3 credits. Prerequisite: permission of instructor. Not offered 1982–83.
3 lecs.
The theoretical foundation of inventory theory. Both single-item, single-location problems and multi-item, multi-echelon inventory systems are analyzed. Topics covered include a study of static and dynamic (s,S) policies under a variety of assumptions concerning the demand process and system structure, as well as computational techniques.]

[764 Deterministic and Stochastic Control Spring. 3 credits. Prerequisite: OR&IE 661 or equivalent. Not offered 1982–83.
3 lecs.
Topics include elements of calculus of variations, Pontryagin's maximum principle, Markov decision processes, dynamic programming. Problems in filtering and prediction, production planning and inventory control, congestion phenomena, storage models, and environmental management are discussed.]

769 Selected Topics in Applied Probability Fall or spring. Credit to be arranged.
Topics are chosen from current literature and research areas of the staff.

[773 Statistical Selection and Ranking Procedures Fall. 3 credits. Prerequisite: OR&IE 674 or permission of instructor. Not offered 1982–83.
3 lecs.
A study of multiple-decision problems in which a choice must be made among two or more courses of action. Major emphasis is on selection and ranking problems involving choosing the "best" category where goodness is measured in terms of a particular parameter of interest. Statistical formulations of such problems; indifference-zone, subset, and other approaches. Single-stage, two-stage, and sequential procedures. Applications. Recent developments.]

779 Selected Topics in Applied Statistics Fall or spring. Credit to be arranged.
Topics chosen from current literature and research interests of the staff.

790 Special Investigations Fall or spring. Credit to be arranged. For individuals or small groups.
Study of special topics or problems.

799 Thesis Research Fall or spring. Credit to be arranged.
For individuals doing thesis research for master's or doctoral degrees.

891 Operations Research Graduate Colloquium Fall or spring. 1 credit.
A weekly 1½-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 893, fall; 894, spring. 1 credit each term.
A weekly meeting of M.Eng. students. Discussion of assigned topics; presentations by practitioners in the field.

Theoretical and Applied Mechanics

Basics in Engineering Mathematics and Mechanics

202 Mechanics of Solids (also Engineering 202) Fall or spring. 3 credits. Prerequisite: coregistration in Mathematics 293.
2 lecs, 1 rec, 4 labs each semester. Evening exams.
See description under Engineering Common Courses.

203 Dynamics (also Engineering 203) Fall or spring. 3 credits. Prerequisites: coregistration in Mathematics 294.
2 lecs, 1 rec, 4 labs each semester. Evening exams.
See description under Engineering Common Courses.

293 Engineering Mathematics (also Mathematics 293) Fall or spring. 3 credits. Prerequisite: Mathematics 192 or 194.
Evening exams (see Mathematics 293).
Partial derivatives and multiple integrals; first- and second-order ordinary differential equations with applications in the physical and engineering sciences.

294 Engineering Mathematics (also Mathematics 294) Fall and spring. 4 credits. Prerequisite: Mathematics 293.
Evening exams (see Mathematics 294).
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.

Engineering Mathematics

310 Advanced Engineering Analysis I Fall and 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.

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, tensor analysis, calculus of variations.

613 Methods of Applied Mathematics IIIa Fall. 2 credits. Prerequisite: T&AM 611 or equivalent. First of an 8-credit sequence (T&AM 613, 614, 615, 616) that develops advanced mathematical techniques for engineering problems.
Review of complex variable theory; conformal mapping; complex integral calculus. Nonlinear partial differential equations; general theory of characteristics.

614 Methods of Applied Mathematics IIIb Spring. 2 credits. Prerequisite: T&AM 613 or equivalent.
Integral transforms for partial differential equations. Green's function; asymptotics, including steepest descent and stationary phase, Wiener-Hopf technique. Problems drawn from vibrations and acoustics, fluid mechanics and elasticity, heat transfer, and electromagnetics.

615 Methods of Applied Mathematics IVa Fall. 2 credits. Prerequisite: T&AM 611 or equivalent.
In context of applications: regular and singular perturbation theory, method of matched asymptotic expansions, two timing (method of multiple scales), WKB approximation.

616 Methods of Applied Mathematics IVb Spring. 2 credits. Prerequisite: concurrent registration in T&AM 614 or equivalent.
In context of applications: Hilbert-Schmidt and Fredholm theories of integral equations, Wiener-Hopf equations with application to finite interval, Carleman equation and its generalization, effective approximations.

Experimental Mechanics

640 Experimental Mechanics Fall. 3 credits.
1 lec.
Each student is expected to perform six to ten experiments in mechanics, selected to meet his or her individual interests. Topics: elastic, viscoelastic, microplastic, and plastic response of materials; linear

and nonlinear vibration of discrete and continuous systems; acoustic and elastic wave propagation and scattering phenomena; dynamical stability of rigid bodies; analog and digital simulation of dynamical systems; magnetoelastic interactions; signal processing.

Continuum Mechanics and Inelasticity

[**450 Introduction to Continuum Mechanics** Fall. Offered alternate years. 3 credits. Not offered 1982–83.
Provides a foundation for further studies in fluid and solid mechanics, materials science, and other branches of engineering. Vector and tensor analysis; kinematics of deformation; analysis of stress and strains; balance laws of physics; constitutive equations; examples of elasticity and fluid mechanics.]

[**651 Continuum Mechanics and Thermodynamics** Fall. 3 credits. Offered alternate years. Not offered 1982–83.
Kinematics, conservation laws, the entropy inequality, constitutive equations, frame indifference, material symmetry. Simple materials and the position of classical theories in the framework of modern continuum mechanics.]

752 Topics in Continuum Mechanics Spring. 3 credits. Prerequisite: T&AM 651. Offered alternate years.
Polymer rheology using functionals or state variables. Continuum theory for rapid shear flows of granular materials. Chemically driven flows, percolation, and finite deformation in biological poro-elastic solids.

[**757 Viscoelasticity and Creep** Fall. 3 credits. Offered alternate years. Not offered 1982–83.
Linear viscoelasticity: constitutive equations, models, differential and integral operators, Laplace transforms, complex modulus, vibrations and wave propagation, boundary-value problems. Thermoviscoelasticity. Creep: classical and modern theories, stress redistribution, boundary-value problems.]

758 Theory of Plasticity Fall. Offered alternate years. 3 credits.
Plastic stress-strain laws, yield criteria, flow rules. Work hardening. Flexure and torsion of bars. Boundary-value problems—thick cylinders, spheres, discs, general 3-D. Residual stress. Limit analysis of structures. Plane strain—slip line theory.

Elasticity and Waves

574 Mechanical Vibrations and Waves Spring. 3 credits.
Two 1½-hour lecs; 4 labs each semester.
Review of vibrations of discrete systems, including multi-degree-of-freedom vibrations. Unified treatment of vibrations and wave phenomena in continuous elastic systems including strings, rods, beams, membranes, and plates. Approximate methods for finding natural modes and frequencies. Dispersion and group velocity. Transient response of discrete and continuous systems.

663 Applied Elasticity Fall. 3 credits.
Two 1½-hour lecs.
Thin curved bars. Plane stress and strain in cylinders; effects of pressure, rotation, and thermal stress. Small (and large) deflection theory of plates; classical, approximate, and strain-energy methods. Thin cylindrical shells. A first course in elastic deformable bodies with numerous engineering applications.

664 Theory of Elasticity Spring. 3 credits.
Two 1½-hour lecs.
Analysis of stress and strain. Airy's stress function solutions using Fourier series and integrals. Torsion theory. Three-dimensional solutions. Bending of prismatical bars. Axially loaded circular cylinder and half space. All topics are illustrated by engineering applications.

666 Fundamentals of Acoustics (also Electrical Engineering 690) Spring. 3 credits.
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. At the level of *Fundamentals of Acoustics,* by Kinster and Frey.

[**765 Mathematical Theory of Elasticity** Spring. Offered alternate years. 3 credits. Prerequisite: T&AM 664. Not offered 1982–83.
The basic equations of large-deformation elasticity; solution of certain large-deformation problems. Linearization. Boussinesq-Papkovich potentials and three-dimensional problems; plane stress by method of Muskhelishvili; conformal mapping; torsion problems.]

768 Elastic Waves in Solids Fall. 3 credits. Offered alternate years.
Two 1½-hour 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-Pekeris. Thick plate theories. Vibration of spheres. Scattering of waves and dynamic stress concentration.

Dynamics and Space Mechanics

570 Intermediate Dynamics Fall 3 credits.
Two 1¼-hour lecs.
Newtonian mechanics for single particles and systems of particles, conservation laws, central-force motion; special relativity; Eulerian mechanics for rigid bodies, tops, gyroscopes; generalized coordinates, D'Alembert's principle, Lagrangian equations, analytic mechanics for particles and rigid bodies.

671 Advanced Dynamics Spring. 3 credits. Prerequisite: T&AM 570 or equivalent. Offered alternate years.
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 (Birkhoff's transformation); canonical transformations and Hamilton-Jacobi theory; Poisson stability and related topics from topological dynamics; Hamilton's principle for continuous systems, applications to shell dynamics.

[**672 Celestial Mechanics (also Astronomy 579)** Fall. 3 credits. Offered alternate years. Not offered 1982–83.
Two 1¼-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.]

[**673 Mechanics of the Solar System (also Astronomy 571)** Spring. 3 credits. Prerequisite: an undergraduate course in dynamics. Offered alternate years. Not offered 1982–83.
Two 1¼-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. Not offered 1982–83.
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, Poincare-Bendixson theorem, indices. 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. Prerequisite: T&AM 675 or equivalent. Offered alternate years. Not offered 1982–83.
Review of planar (single-degree-of-freedom) systems. The concept of dynamical systems, local and global analysis. N-dimensional systems, types of solutions, Poincaré maps, stability. Structural stability and bifurcations in planar systems. Discrete dynamical systems, maps and difference equations, homoclinic and heteroclinic motions, the Smale Horseshoe and other complex invariant sets. Implications for systems of dimension greater than three, 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

491–492 Project in Engineering Science 491, fall; 492, spring. 1 to 4 credits, as arranged.
Projects for undergraduates under the guidance of a faculty member.

798 Selected Topics in Theoretical and Applied Mechanics Fall. 1–4 credits, as arranged.
Special lectures or seminars on subjects of current interest. Topics are announced when the course is offered.

799 Topics in Theoretical and Applied Mechanics —Fracture Mechanics Spring. 3 credits.
Introduction to linear elastic fracture mechanics. Topics covered are linear elastic crack problems, crack-tip fields, stress-intensity factor, and energy-release rate. The second part of the course covers nonlinear fracture mechanics. Topics covered are small-scale yielding; J integral, crack-tip fields, elastic plastic crack solutions, analysis of crack growth, and time-dependent fracture mechanics.

890–990 Research in Theoretical and Applied Mechanics Fall or spring. 1–6 credits; 890: 1–9 credits; 990: as arranged.
Thesis or independent research at the M.S. (890) or Ph.D. (990) level on a subject of theoretical and applied mechanics. Research is under the guidance of a faculty member.

Faculty Roster

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