Cornell University Announcements College of Engineering 1971-72

Cornell University

College of Engineering

1971-72

Cornell University Announcements

Volume 63 of the Cornell University Announcements consists of twenty-three catalogs, of which this is number 12, dated Aug. 27, 1971. Publication dates: twenty-three times a year (four times in August and October; three times in March and November; twice in July and September; once in January, April, May, June, and December). Publisher: Cornell University, Sheldon Court, 420 College Avenue, Ithaca, New York 14850. Second-class postage paid at Ithaca, New York.

Contents

The courses and curricula described in this *Announcement*, and the teaching personnel listed herein, are subject to change at any time by official action of Cornell University.

Further Information

Undergraduates

All prospective engineering students should write for a copy of the *Announcement of General Information,* which describes the University community in greater detail. *Engineering at Cornell,* an illustrated *Announcement,* has been prepared especially for precollege students, and it too may be obtained by writing Cornell University Announcements, Day Hall, Ithaca, New York 14850.

Graduates

The *Announcement of the Graduate School* should be consulted for additional information regarding admission, financial aid, and degree requirements. It may be obtained by writing Cornell University Announcements, Day Hall, Ithaca, New York 14850.

Also available is an illustrated brochure, *Graduate Study in Engineering and Applied Sciences,* which contains information on various research programs and areas of study. This may be obtained by writing The College of Engineering, Carpenter Hall, Cornell University, Ithaca, New York 14850.

Cornell Academic Calendar

1971–72

Registration, new students	Thursday, September 2
Registration, continuing and rejoining students	Friday, September 3
Fall term instruction begins, 7:30 a.m.	Monday, September 6
Thanksgiving recess:	
Instruction suspended, 1:10 p.m.	Wednesday, November 24
Instruction resumed, 7:30 a.m.	Monday, November 29
Fall term instruction ends, 1:10 p.m.	Saturday, December 11
Independent study period begins, 2:00 p.m.	Saturday, December 11
Final examinations begin	Thursday, December 16
Final examinations end	Thursday, December 23
Christmas recess and intersession	
Registration, new and rejoining students	Thursday, January 20
Registration, continuing students	Friday, January 21
Spring term instruction begins, 7:30 a.m.	Monday, January 24
Spring recess:	
Instruction suspended, 1:10 p.m.	Saturday, March 18
Instruction resumed, 7:30 a.m.	Monday, March 27
Spring term instruction ends, 1:10 p.m.	Saturday, May 6
Independent study period begins, 2:00 p.m.	Saturday, May 6
Final examinations begin	Monday, May 15
Final examinations end	Monday, May 22
Commencement Day	Friday, May 26

The dates shown in the Academic Calendar are subject to change at any time by official action of Cornell University.


HOLLISTER HALL

Cornell University

College of Engineering

In modern engineering, the one constant factor is change: change so swift that the engineering student must be offered a dynamically flexible education. In its long, distinguished history, the College of Engineering at Cornell has consistently offered such an education.

Engineering courses have been taught at Cornell since the University was founded more than one hundred years ago. At that time, Cornell was regarded as a radical experiment in higher education, teaching subjects like engineering and agriculture as well as the humanities. The University's founder and first benefactor, Ezra Cornell, was convinced, however, that the classics and the more practical "mechanic arts" would thrive together and that the nation needed citizens educated in both. Mr. Cornell himself had considerable experience in engineering work. For Samuel F. B. Morse, he had laid the first telegraph line between Baltimore and Washington, and later he became a major stockholder in the Western Union Telegraph Company. The motto Mr. Cornell gave to his university—"I would found an institution where any person can find instruction in any study"—was the first clear statement of what we now conceive to be the true university concept in higher education.

In addition to the College of Engineering, Cornell University has six other divisions to which secondary-school graduates are admitted: Agriculture; Architecture, Art, and Planning; Arts and Sciences; Hotel Administration; Human Ecology; and Industrial and Labor Relations. Graduate education at Cornell is administered by the Graduate School and by the professional or graduate divisions in law, veterinary medicine, business and public administration, nutrition, nursing, and medicine. All but the last two divisions (which are in New York City) are in Ithaca, New York, on a campus that is generally regarded as one of the most beautiful in the United States.

Engineering students at Cornell, whether graduate or undergraduate, are not only a part of a distinguished engineering college but also a part of the larger University; they may, of course, draw upon the course offerings of other divisions of Cornell.

The University has no requirements which force students into the same educational mold. The College of Engineering provides society with engineers whose combined capabilities are as broad and continuous as those of the engineering profession itself.

Cornell has produced many engineering firsts: it developed the first undergraduate electrical engineering program in the nation and pioneered in the early development of curricula in industrial engineering, mechanical engineering, and engineering physics. In addition, Cornell was the first to award graduate degrees in engineering, granting the degree of Civil Engineer in 1870 and, in 1872, the first doctorate in civil engineering. The latter was the first Ph.D. awarded at Cornell in any graduate study. In 1885, the first Ph.D. in electrical engineering was granted, and in 1886, one of the first major national scientific fraternities, Sigma Xi, was founded at Cornell.

Today, approximately 2,100 undergraduate engineers are enrolled in the various schools and departments of the College of Engineering. In addition, about 670 full-time students are working on advanced degrees in areas covering every portion of the engineering profession. Two hundred engineering faculty members, complemented by the faculties in the University's various mathematics and science departments, give strong support to all engineering students.

The rapid acceleration of the growth of modern science and technology poses a complex and exciting challenge for engineering education. Every division of the College is committed to offering the best possible undergraduate programs and to advancing graduate education and research; in this way, Cornell engineers are provided with the foundation essential for active and rewarding professional careers.

Organization of the College

The College of Engineering offers degree programs at each of the following levels: Bachelor

One of the ten modern buildings on the Engineering Quadrangle of Science, Master of Engineering, Master of Science, and Doctor of Philosophy. To carry out the aims of each of these degree programs, the faculty of the College of Engineering is organized into schools, departments, and graduate Fields.

Generally, a school or department is responsible for definition and subsequent supervision of the undergraduate curriculum in its area of engineering. In addition, the faculty of a school is responsible for the professional Master's degree program, the Master of Engineering.

For Master of Science and doctoral programs the University faculty is organized into graduate Fields. (See p. 11 for those Fields associated with the faculty of the College of Engineering.)

Facilities

Buildings and Laboratories

A complex of modern buildings, most of them on the Engineering Quadrangle, provide accommodations for engineering teaching and research. Several of these buildings have been gifts from distinguished Cornell alumni.

Administrative offices and the Engineering Library are located in *Carpenter Hall.* The School of Chemical Engineering is housed in *Olin Hall,* and the School of Electrical Engineering in *Phillips Hall. Hollister Hall,* the main facility of the School of Civil and Environmental Engineering, also houses offices of the Division of Basic Studies and the Engineering Counseling Center.

Instruction, research, and the testing of materials and structural elements are conducted in three attached buildings, *Thurston, Kimball,* and *Bard Halls.* Bard Hall contains most of the laboratories and classrooms of the Department of Materials Science and Engineering. Thurston Hall facilities are used by the Department of Theoretical and Applied Mechanics and by the Department of Structural Engineering of the School of Civil and Environmental Engineering. The University's Department of Geological Sciences occupies part of Kimball Hall.

Upson Hall houses the Sibley School of Mechanical Engineering, the School of Industrial Engineering and Operations Research, and the University's Department of Computer Science. A remote terminal in the basement of Upson Hall is connected to the University's IBM 360 Model 65 computer, located some three miles from the central campus. Computer work may be done directly at this Upson Hall terminal.

Cornell's *Ward Laboratory of Nuclear Engineering,* housing both a TRIGA and a "zero-power" reactor, a gamma irradiation cell, and a low-energy ion accelerator, is on the Engineering Quadrangle.

Facilities of the School of Applied and Engineering Physics, and many of its research laboratories, are located in *Clark Hall,* which serves the University's Department of Physics.

Research in various aspects of plasma physics is conducted through the *Laboratory of Plasma Studies,* which facilitates interdisciplinary work in plasma, electron, and laser physics. Other research laboratories for plasma studies are located in Grumman, Upson, and Phillips Halls.

More detailed descriptions of facilities for each of the instructional areas in the College may be found within the section, Areas of Instruction.

Library Resources

The Engineering Library, in Carpenter Hall, houses approximately 125,000 books and periodicals, a collection which reflects the needs of the many schools and departments of the College of Engineering. Among the specialized holdings of the Engineering Library are a full depository collection of the United States Atomic Energy Commission, the Kuichling Library of Sanitary Engineering, and the Water Resources Collection. For patent research, the library maintains a file of the British patents and sets of the Official Patent Gazette of the United States Patent Office and the Canadian Patent Office Record (patent abstracts).

A special feature of the Engineering Library is the browsing room, a paneled and attractively furnished room containing about 1,500 selected books in the fields of the humanities and the social sciences.

Allied and supporting literature in the basic sciences is available in the physical sciences library in Clark Hall and in the mathematics library in White Hall. The total library resources of the University include more than 3,600,000 volumes.

Academic Programs

Undergraduate Degree Program

The purposes of the undergraduate program in engineering at Cornell are to provide an educational basis that will support the increasing range of activity undertaken by engineers in all forms of human endeavor and to accommodate the rapid change taking place in all the established fields of engineering.

Bachelor of Science Degree

The undergraduate degree of Bachelor of Science is granted by the College of Engineering upon the completion of four years of study. The student obtains this degree by spending his first two years in the Division of Basic Studies preparing for his entry into one of seven *Field Programs* or the *College Program,* in which he will spend two additional years completing the requirements for his undergraduate degree. An exception is the program in agricultural engineering, which is administered jointly by the Colleges of Engineering and Agriculture: students are enrolled in the College of Agriculture for the first three years, and in the College of Engineering during the fourth year.

Common Studies Core

One of the goals of the curricula is to foster the development of a sound education which can be directed toward a wide choice of careers in engineering and applied science. Studies during the junior and senior years, as well as subsequent graduate work in the College, complement the course work included in the core. Two-thirds of the credit hours in the College's undergraduate programs are included in this core, with the remainder devoted to the development of a specific educational goal in either one of several *Field Programs* (see pp. 19–50) or the *College Program* (see p. 31).

In the core curriculum of the College, one course in physics, one course in chemistry, and two courses in mathematics are required of all freshmen. Two electives are chosen by the student each term in the freshman year; one must be in the humanities and the other in any natural or contextually relevant social science. The latter must be approved by the Core Curriculum Committee. Students wishing to take an additional course in physics and/or chemistry during their freshman year may elect one as a substitution for their natural science elective. In addition, an introductory engineering course (Engineering 105, 106) is required in each term of the freshman year.

For sophomores, two courses in mathematics and two courses in physics are required. Each student elects two engineering core sciences each term; only one of these four may be specified as a prerequisite for entry to a Field Program in the junior year. A humanities or social science course is also elected by the sophomore each term.

After completing the sophomore year, a Cornell engineering student may enroll in one of the several Field Programs or the College Program. In either option, he continues work in the core by including twelve credit hours of liberal studies electives and six credit hours of unspecified electives in his junior and senior year programs.

At present, Field Programs are offered in chemical, civil and environmental, electrical, and mechanical engineering; industrial engineering and operations research; engineering physics; and materials science and engineering. To prepare for entry into one of these Field Programs, the student should select the appropriate one-term engineering science course during his sophomore year (see the Basic Studies curriculum, p. 20). Approximately thirty percent of the four-year program is devoted to professional studies in a chosen field.

Upperclass Curricula

During his junior and senior years, the engineering undergraduate enters one of the College's schools or departments for specialized study in a particular area. The student enrolls in one of the following upperclass programs, which include seven Field Programs and the College Program:

Chemical Engineering (see p. 27).

Civil and Environmental Engineering (see p. 29).

Electrical Engineering (see p. 34).

Engineering Physics (see p. 24).

Industrial Engineering and Operations Research (see p. 38).

Materials Science and Engineering (see p. 40).

Mechanical Engineering (see p. 42).

College Program (see p. 31). Administered by the College Program Committee of the College of Engineering, this flexible curriculum accommodates unique and well-defined objectives in engineering not served by one of the areas listed above.

The Engineering Cooperative Program

The basic premise of the Engineering Cooperative Program at Cornell is that industry can play a major role in a student's education by providing him with work assignments appropriate to his interests and training. Under this Program an undergraduate engineering student can obtain almost a full year of professional experience without extending the date of his graduation. More than 600 Cornell engineers have participated in this Program since its inception in 1947.

Students enrolled in the Program spend alternating periods in college and in industry after the sophomore year. By utilizing the three summers that follow completion of the sophomore year, three work periods, totaling nearly a calendar year, are provided. On the following schedule they are designated I, II, and III, respectively.

Summer	Fifth Term Courses
Fall (Junior Year)	Industry I
Spring (Junior Year)	Sixth Term Courses
Summer	Industry II
Fall (Senior Year)	Seventh Term Courses
Spring (Senior Year)	Eighth Term Courses
Bachelor of Science Degree	
Summer	Industry III

By the end of the summer following his graduation, the student is ready to accept a professional position or begin graduate work. Graduate study leading to the Master of Engineering degree can, for example, begin in the fall term.

While on a work assignment, the student earns a substantial salary, and gains industrial experience that complements classroom knowledge and facilitates the transition from college to industry. Because the Program emphasizes the development of the individual and his abilities, the student works for only one company during the three industry periods. However, neither the student nor the company is obligated in any way after completion of the Program. Having participated in the Program, the graduate can expect his initial level of responsibility and salary to be greater than he might otherwise receive.

Companies participating in the Engineering

Cooperative Program include the following: American Electric Power Service Corporation; AVCO Everett Research Laboratory; Chicago Pneumatic Tool Company; Clairol Incorporated; Cornell Aeronautical Laboratory; Eastman Kodak Company; Emerson Electric Company; General Electric Company (Binghamton, Schenectady, and Syracuse); The Gleason Works; Hewlett-Packard Company (New Jersey Division and Medical Electronics Division); International Business Machines Corporation; Kurt-Salmon Associates, Inc.; Moore Products Company; Raytheon Company, Sanders Associates, Inc.; United Air Lines; Xerox Corporation.

Admission to the Program is open to any fourth-term student who has chosen electrical engineering, engineering physics, industrial engineering and operations research, or mechanical engineering as his field and who meets the following requirements: (1) a sound scholastic performance at the time of admission to the Program and (2) an invitation from one of the participating companies based on an individual interview.

Further information about the Program may be obtained from the Engineering Cooperative Program Office, 106 Upson Hall.

Study in France: An Exchange Program

Junior engineering students are eligible to participate in a student exchange program which the College of Engineering operates with the École Nationale Supérieure de Mécanique et d'Aérotechnique (ENSMA) in Poitiers, France.

ENSMA is a small school, with a student body of around eighty, which is closely associated with a large university in Poitiers (about 150 miles southwest of Paris). Its principal specialties are mechanical, thermal, and aerospace engineering, and there is also an emphasis on computer use and technology. Recent Cornell participants have included students majoring in engineering physics and mechanical engineering, as well as some in the College Program.

Because the Cornell exchange students live among French students and take their instruction entirely in French, good facility in the language is essential. Some of the Cornell participants have spent one or two months during the preceding summer at a language school in France.

Each participating student pays Cornell tuition and fees (minus any applicable scholarship support) and room and board expenses at the usual rate here. The program is coordinated by Professor Benjamin Gebhart, 224 Upson Hall.

Preparation for Graduate Study

The Bachelor of Science degree in a Field Program or a College Program may be the terminal point in the formal education of some students; however, it is expected that most will seek to continue studies beyond this level.

At the completion of the undergraduate degree requirements, a student may apply for admission to the College's professional Master's degree program and can earn that degree in one additional year. The degree requirements include advanced work begun formally during the junior year, and thus the degree represents a three-year program of integrated studies in a particular field. The program is designed to meet the requirements of modern engineering practice, and the professional Master's degree represents the level at which graduates will be prepared to seek professional engineering employment.

Individuals seeking careers in research, in applied science, or in a specialized engineering area, such as thermal engineering within mechanical engineering, can apply for the Master of Science or the Doctor of Philosophy program at the end of the four-year Bachelor's program. Some students may want to undertake graduate or professional study in other fields such as education, law, business, public administration, city and regional planning, or medicine. Each student decides for himself which level of preparation he seeks in engineering—the Bachelor of Science or professional Master's degree—before embarking on other studies.

Graduate Degree Programs

Two distinct graduate programs are offered by the College of Engineering. One is a *professional* program leading to the degree of Master of Engineering, and the other is a *research-oriented* program leading to the degrees of Master of Science and Doctor of Philosophy.

Master of Engineering

Graduates intending to prepare for professional engineering careers in one of the several engineering fields generally seek the professional degree. Cornell's undergraduate Field Programs, coupled with a professional Master's program, offer an integrated curriculum of three years, following completion of the two-year Basic Studies program, to those who seek professional competence. This degree, administered by the Engineering Division of the Graduate School unless noted otherwise, may be taken in any of the following areas:

Aerospace Engineering (see p. 21). Administered by the Graduate School of Aerospace Engineering.

Agricultural Engineering (see p. 24).

Chemical Engineering (see p. 28).

Civil Engineering (see p. 30).

Electrical Engineering (see p. 37).

Engineering Mechanics (see p. 49).

Engineering Physics (see p. 26).

Industrial Engineering (see p. 40).

Materials Engineering (see p. 42).

Mechanical Engineering (see p. 45).

Nuclear Engineering (see p. 46).

Master of Science and Doctor of Philosophy

The general degrees of Master of Science and Doctor of Philosophy, administered by the Graduate School of the University, are oriented toward students seeking academic or research careers, and require submission of a thesis on research conducted under the direction of a faculty member. Details of admissions, residence requirements, and financial aid are given in the *Announcement of the Graduate School* (see p. 4 for the address).

Programs of study are organized under graduate Fields, most of which coincide with the respective engineering schools or departments. The graduate Fields that may be of interest to engineering students are listed below, with associated major and minor subject areas. Prospective candidates are invited to write to the graduate Field representative of the Field in question for detailed information.

Aerospace Engineering: Aerospace Engineering, Aerodynamics

Agricultural Engineering: Agricultural Engineering, Agricultural Structures, Agricultural Waste Management, Electric Power and Processing, Power and Machinery, Soil and Water Engineering

Applied Mathematics

Applied Physics

Chemical Engineering: Biochemical Engineering, Chemical Engineering (General), Chemical Microscopy, Chemical Processes and Process Control, Materials Engineering, Nuclear Process Engineering

Civil and Environmental Engineering: Aerial Photographic Studies, Environmental Systems Engineering, Geodetic and Photogrammetric Engineering, Geotechnical Engineering, Hydraulics and Hydrology, Sanitary Engineering, Structural Engineering, Structural Mechanics, Transportation Engineering, Water Resource Systems

Computer Science: Computer Science, Information Processing, Numerical Analysis, Theory of Computation

Electrical Engineering: Electrical Engineering, Electrical Systems, Electrophysics

Geological Sciences

Materials Science and Engineering: Materials and Metallurgical Engineering, Materials Science

Mechanical Engineering: Machine Design, Materials Processing, Thermal Power, Thermal Processes

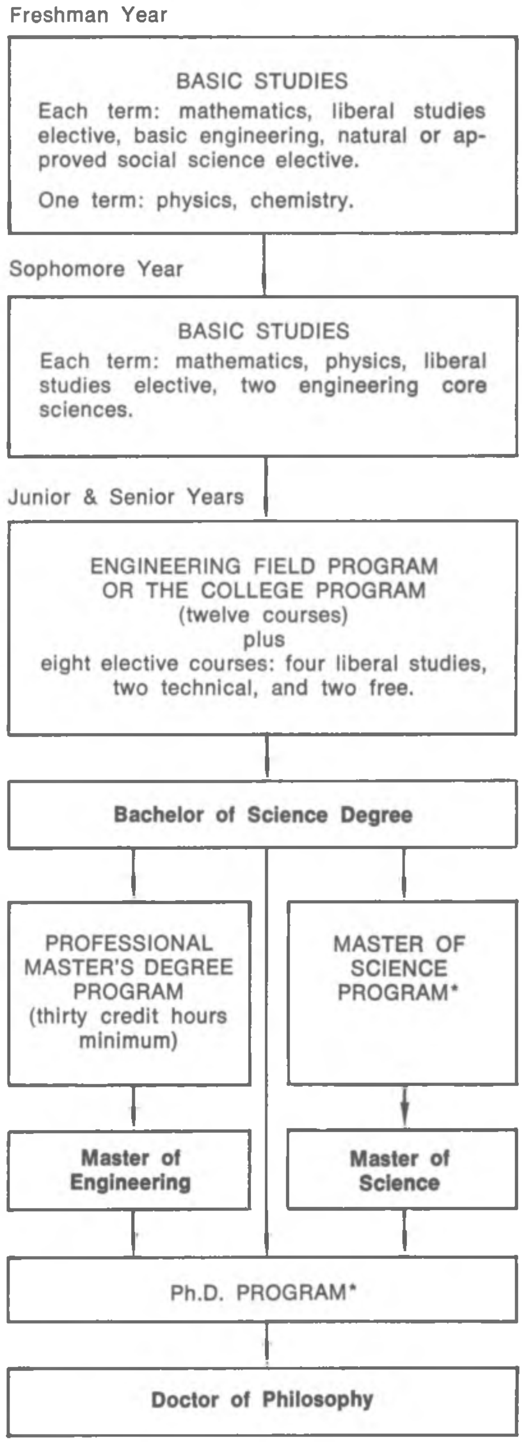
Nuclear Science and Engineering: Nuclear Engineering, Nuclear Science

Operations Research: Applied Probability and Statistics, Industrial Engineering, Information Processing, Operations Research, Systems Analysis and Design

Theoretical and Applied Mechanics: Fluid Mechanics, Mechanics of Materials, Solid Mechanics, Space Mechanics

Water Resources

Summary of Degree Requirements for B.S., M.Eng., M.S., and Ph.D.



* Consult the *Announcement of the Graduate School* for detailed requirements for the M.S. and Ph.D. degree programs.

Grading

The University uses quality points to compile a student's grade-point average and scholastic rank. A grade point of 4.0 is equivalent to an A; a 3.0 to a B; a 2.0 to a C; and a 1.0 to a D. No quality points are assigned to failing grades. A "plus" grade is given an additional 0.3 increment; e.g., a B+ is worth 3.3 points. A "minus" grade is given a –0.3 increment; e.g., a C– is worth 1.7 points. Grades of S (satisfactory) and U (unsatisfactory) are sometimes given, but they do not figure into a student's weighted academic average.

Any undergraduate, after his first term of freshman residence, may take one of his five courses (a humanities or social sciences elective) on an S/U basis upon approval of the instructor in the course and his faculty adviser. The purpose of the S/U option is to enable engineering students to enroll in somewhat advanced-level courses or those normally taken by a large number of students who have a major in the field without being penalized, in terms of grade-point average, for a limited background.

To attain the dean's honor list in the College of Engineering, an undergraduate must have attained an average of at least 3.25, based on at least twelve credit hours in which letter grades other than S and U have been awarded.

Continuing Education Activities

The College's Office of Continuing Engineering Education provides special programs for engineers and scientists in industry, research institutes, private practice, government agencies, and colleges and universities. The growing flood of technical information makes it impossible for the average engineer to keep his knowledge current except perhaps in a narrow specialty. Many engineers rise to positions in technical management in which they must direct the activities of a variety of specialists. For such work they must be conversant with the concepts and vocabulary of many different disciplines. Because of the constant changes in undergraduate and graduate curricula, the manager who is ten years out of school often finds it difficult to communicate effectively with newly graduated engineers even within his own specialty. Unless given opportunities to update his knowledge, the engineer will soon find his professional abilities inadequate.

Cornell programs to provide these opportunities include in-plant courses for firms in the Ithaca area; short courses and workshops in various technical subjects; and programs for specific industries. No academic credit is given for most of the programs.

Courses entitled Modern Engineering Concepts for Technical Managers are offered annually, both in the plant and on the Cornell campus. These courses consist of thirty to fifty lecture-seminars on topics in mathematics, materials science, operations research, electronics and solid state devices, nuclear engineering, bioengineering, and other areas. The courses emphasize breadth, not depth, and provide a resource from which to draw ideas and direction for effective technical management.

Intensive short courses, three days to two weeks long, are offered in various technical subjects each summer. Sixteen courses were offered in 1971; the subjects included topics in computer science, structural design, microscopy, control of water-borne wastes, environmental effects of nuclear power production, design of small reservoirs, heat pipes, mechanical design, and interpersonal relations for managers. Participants in these courses are drawn from many different states and foreign countries.

Short courses and workshops, primarily designed for engineers in the construction industry, are held on the Cornell campus each January. A two-week program in construction engineering management includes lectures on statistics, applications of operations research, and other technical developments, coupled with sessions on corporate finance, contract law, labor relations, and other topics of concern to construction engineers. In 1971 workshops were also held on the inventory rating of existing bridges and on developments in the design and installation of water, sewer, and drainage lines.

Further information about any of these programs may be obtained from the Office of the Director of Continuing Engineering Education, 251 Carpenter Hall.

Admission

Freshman Admission

Detailed information concerning the procedures of undergraduate admission is given in the *Announcement of General Information* and in the *Guide for Candidates* (included with each application form). Important dates for applicants include:

Admission applications due: Regular, February 15; Early Decision Plan, November 1.

Admission decisions announced: Regular, as decisions are made in February, March and the first half of April; Early Decision Plan, December 1.

Financial aid applications due: Regular, January 15; Early Decision Plan, November 1.

Financial aid decisions announced: Regular, by mid-April; Early Decision Plan, December 1.

Date by which applicant must advise Cornell of his decision (for admission *and* financial aid): Regular, May 1; Early Decision Plan, applicants will be advised of date.

Secondary School Credits

Sixteen units of college-preparatory subjects are required. The following fourteen units must be included:

Subject	*Units**
English	4
History	2
One foreign language	2
Algebra (elementary and intermediate)	2†
Plane geometry	1†
Trigonometry	½†
Advanced algebra or solid geometry	½†
Chemistry	1
Physics	1

* A unit is one year of study, made up of 120 hours of classroom work; that is, a minimum of 160 class periods if each is forty-five minutes long.

† The mathematics units listed above may be taken as separate courses or may be included in four units of comprehensive college-preparatory mathematics.

College Entrance Examination Board Tests

The Scholastic Aptitude Test of the College Entrance Examination Board is required of all freshman applicants. In addition, Achievement Tests in mathematics (Level I or Level II) and in chemistry *or* physics are required of all applicants. These must be taken *not later than January* of the last year in secondary school. Generally, it is recommended that the Achievement Test in science be taken in May of the junior year, in that science in which the applicant is enrolled. The admissions committee will, however, consider the Achievement Test in science which is taken in December or January of the senior year for a course completed in the junior year, or earlier, or for a course currently in progress. Test results for students in these circumstances are compared with those for a similar group and are not expected to be as high as results of tests taken at the time of completion of a full year's work. *Applicants should not defer this test requirement until March or May of the senior year.* Results from those testing dates will be received too late to be useful to the admissions committee.

It may be noted that in some special circumstances it is possible for a student to be considered on the basis of testing by the American College Testing Program (ACT). A student who feels that he might qualify for consideration based on ACT scores should send a letter of explanation and a request for waiver of College Entrance Examination Board score report requirements to Chairman, Engineering College Admissions Committee, 223 Carpenter Hall, Cornell University, Ithaca, New York 14850.

Other Factors

Three factors are considered in the review of each candidate. The first factor is academic and includes, in addition to the College Entrance Examination Board results indicated above, the applicant's high school grades, rank in class, and other available academic data. The second and third factors are personal qualities and demonstration of a well-considered desire and well-founded commitment to study engineering.

Personal qualities that are considered may include leadership capabilities and intellectual creativity. Significant participation in extracurricular activities and recommendations by counselors may also be considerations. A student's commitment to engineering is evidenced by the extent of his investigation of the field and his understanding of the implications of an undergraduate professional education.

The admissions committee tries to judge whether a student has the maturity and the study and work habits that are necessary for successful work in an engineering curriculum. Superior grades or high College Entrance Examination Board scores are in themselves no guarantee of success, nor are they alone a guarantee of admission.

Advanced Placement

Through cooperation with the advanced placement program of the College Entrance Examination Board, and on the basis of departmental tests given during the fall orientation period, normally one-fifth of the class is given advanced placement and actual college credit for one or more courses of the freshman year. This makes possible the development of a more individual program with a broader liberal component or more advanced technical studies.

Superior students who have achieved two terms of advanced placement in mathematics and in either chemistry or physics upon graduation from high school may find it possible to enroll at the sophomore level. Eligibility to seek advanced placement is not restricted to those who have had a high school course specifically labeled "Advanced Placement." Many types of enriched or accelerated programs provide the substance for earning advanced standing.

Transfer Admission

Students who wish to transfer to the Cornell College of Engineering from other universities or colleges are invited to communicate with the Chairman, Transfer Admissions Committee, Carpenter Hall, Cornell University, Ithaca, New York 14850. A maximum of two years of transfer credit may be applied toward a Cornell degree.

Students who are accepted for transfer on the basis of completion, with better-than-average records, of two terms or three quarters of academic work in other collegiate institutions will be awarded credit for thirty-four hours. However, there may be a stipulation that certain courses normally taken in the freshman year be completed as free electives before graduation. Similarly, above-average students who are accepted on the basis of completion of four terms or six quarters in other institutions will be awarded credit for sixty-eight hours, with the provision that certain underclass courses be completed as free electives before graduation. In the case of students who are accepted for transfer admission but have only average academic records, individualized course credit evaluations will be made. University policy prohibits the granting of transfer credit for any course for which the student received a grade below C–.

A special scholarship program has been developed for United States citizens who are currently enrolled in community or junior colleges and are interested in transfer admission. In order to qualify for this special scholarship program, applicants must substantiate financial need in addition to being granted transfer admission to the College of Engineering. As with all financial assistance, the amount of these special scholarships varies with each individual, depending upon his demonstrated financial need. A Parents' Confidential Statement (PCS), available from the College Scholarship Service at Princeton, New Jersey, must accompany the scholarship application.

Applicants for transfer from two-year colleges who are interested in the special scholarship program should apply no later than April 15. There is no specific deadline for applications for transfer from four-year institutions.

Special Students

In exceptional cases, individuals who do not wish to become candidates for an undergraduate degree may be admitted as special students. Persons who cannot meet the usual entrance requirements or who do not wish to spend the time required to complete a degree may qualify, but they must have had some engineering training and must satisfy the prerequisites for the courses they wish to take. Other applicants may have baccalaureate degrees but wish to pursue further work at the undergraduate level. In any case, a prospective special student should write to the director of the professional school to which he wants to be admitted.

Graduate Admission

An applicant for admission to a graduate degree program in engineering must hold a baccalaureate or equivalent degree from a college or university of recognized standing. Such a student may enter as a candidate for either of the general degrees (Master of Science or Doctor of Philosophy) or for the professional engineering degree—Master of Engineering (Aerospace, Agricultural, Chemical, Civil, Electrical, Engineering Mechanics, Engineering Physics, Industrial, Materials, Mechanical, or Nuclear).

General Degrees

The Master of Science and Doctor of Philosophy degrees are available in all fields and subdivisions of the College of Engineering (see pp. 10–11). They are administered by the Graduate School and require work in both major and minor fields of study, as well as the completion of a satisfactory thesis, usually involving individual and original research. A prospective graduate student interested in obtaining an M.S. or Ph.D. degree should consult the *Announcement of the Graduate School* for additional information concerning these degrees and should correspond with the professor supervising the particular field of engineering representing his major interest. Students who do not completely meet the entrance requirements for these degrees may be admitted as provisional candidates or without candidacy according to previous preparation, but they must in all cases hold a baccalaureate or equivalent degree.

Professional Master's Degrees

Professional degrees at the Master's level are offered in aerospace, agricultural, chemical, civil, electrical, industrial, materials, mechanical, and nuclear engineering and in engineering mechanics and engineering physics. All except the degree in aerospace engineering are administered by the Engineering Division of the Graduate School. The Master of Engineering (Aerospace) degree is granted on the recommendation of the faculty of the Graduate School of Aerospace Engineering; prospective candidates for this degree should apply directly to the director of the Graduate School of Aerospace Engineering.

These degrees are intended primarily for persons who plan to practice engineering and not for those who expect to enter engineering teaching or research. The student with a baccalaureate degree in the area of engineering or science deemed appropriate to his proposed field of study may become a candidate for a professional degree. The degree of Master of Engineering is the first engineering degree (the Bachelor of Science after four years of study is not designated as an engineering degree) and is the one accredited by the Engineers' Council for Professional Development.

The professional degrees require a minimum of thirty credit hours of graduate-level work in the principles and practices of the specific field. They do not require the presentation of a thesis; they do, however, require completion of an engineering design project that may be worked on individually or in groups of up to four students, and submission of a formal report on the project. Each program also requires completion of a curriculum of related technical courses, differing in content among the several professional fields. Each curriculum includes some prescribed and some elective courses, with considerable flexibility to permit adaptation to the special needs of the individual student. A cumulative grade-point average of at least 2.5 (see p. 12) is required for good standing in the program, and for recommendation for the degree.

At Cornell this one-year program is integrated with the undergraduate program, and, after receiving their baccalaureate degrees, many students continue for the fifth year. Regular application for the Master of Engineering degree program must be made, however. The Cornell graduate will generally be admitted if he has a cumulative grade-point average of at least 2.3, with an average of at least 2.0 for each of the last three terms, and if he has demonstrated by his performance in his major field that he has the ability to be successful in graduate study.

Further information and application forms may be obtained by writing to Graduate Professional Engineering Programs, College of Engineering, 221 Carpenter Hall.

Expenses and Financial Aid

Expenses

Estimated expenses for a student in the College of Engineering for the 1971–72 academic year total $5,000, which includes $2,800 for tuition and fees, an estimated $1,500 for room and board, $650 for personal expenses, and the $50 registration fee. Additional details concerning these expenses, method of payment, refunds, and other matters of financial interest are given in the *Announcement of General Information.*

Undergraduate Financial Aid

Substantial aid in the form of scholarships, loans, and employment is available to help students meet the cost of their education. Over two-thirds of all undergraduate engineering students receive financial aid, and the total resources available for these students amount to about one and three quarters of a million dollars a year.

Freshman Applicants

Over $400,000 in scholarship grants will be awarded this year to incoming College of Engineering freshmen. Loans and jobs will increase the total amount of financial aid for engineering freshmen to about $550,000. The College follows a policy of full-need awards; that is, no award will be made unless a package of scholarship, loan, and occasionally a job can be provided to equal calculated need. The total financial aid package may be as high as $4,500 a year.

Freshmen seeking financial aid should complete the financial aid application form and file it, still attached to the admissions application, with the University Office of Admissions. The Parents' Confidential Statement of the College Scholarship Service must also be filed.

No student should refrain from applying for *admission* because of financial circumstances. Admissions decisions are rendered without regard for financial aid requirements; after admission has been granted, applicants for financial aid are considered for the available funds.

Upperclassmen

For upperclassmen who *did not* receive aid as incoming freshmen, there are extremely limited sources of financial aid. The appropriate application forms may be obtained from the University Office of Scholarships and Financial Aid.

Transfer Students

A special scholarship fund has been established for students transferring to the Cornell College of Engineering from junior and community colleges. This fund is restricted to citizens of the United States. Further information may be obtained by writing to Chairman, Transfer Admissions Committee, Carpenter Hall.

Scholarship Resources

The largest single source of assistance for engineering students is the John McMullen Scholarship Fund. In any given year more than 500 undergraduates receive support from this fund; total expenditures for their scholarships exceed one million dollars annually.

The McMullen Fund and other major resources which provide scholarships specifically for engineering students are listed in the chart, pp. 16–17. Each applicant files only one application; the Engineering Scholarship Committee attempts to assign specifically designated awards to those students whose qualifications most nearly match the donor's wishes.

In addition to these special engineering scholarships, there are University-wide scholarships for which accepted engineering applicants are eligible. These include the Cornell National Scholarship and the General Motors Scholarship.

Graduate Financial Aid

Financial aid to graduate students is available in several forms: fellowships and scholarships, research or teaching assistantships, residence hall assistantships, and loans.

Graduate students whose major subjects are in the various branches of engineering and who wish to be candidates for scholarship or fellowship aid should consult the *Announcement of the Graduate School* and make application to the dean of the Graduate School. Those who are candidates for the professional degrees should apply to the director of the appropriate field. Information relating to application for the other forms of financial aid mentioned above will also be found in the *Announcement of the Graduate School.*

Student Personnel Services

Advising and Counseling

The University provides extensive personnel services and counseling facilities for all students. Among these are the Office of the Dean of Students, the University Health Services, the Reading-Study Center, the Guidance and Testing Center, the Religious Affairs Office, the Career, Summer Plans, and Placement Center, and the Office of Scholarships and Financial Aid.

The College of Engineering operates the *Engineering Counseling Center,* located at 105–107 Hollister Hall. In addition to being an educational information resource center for all students in the College, it has a small staff of upperclass engineers who are available to freshmen and sophomores seeking advice and assistance. A monthly newsletter, *News Briefs,* containing information on various academic activities and programs, is distributed to all freshman and sophomore engineers. Each engineering student has a faculty adviser who can assist in personal counseling and on questions pertaining to his educational programs or career goals. Students are also encouraged to confer with the deans, directors, and other faculty members of the College on any educational or personal matter.

The Office of Engineering Admissions, Carpenter Hall, is the focal point in the College for the admission of freshman students, the administration of the engineering scholarship funds, the placement of graduating students, and the compilation and maintenance of alumni records. Any student is welcome to consult the director of the Office on nonacademic matters. Special provision is made for questions relating to financial aid and placement.

Placement

The facilities of the University Career, Summer Plans, and Placement Center are available to all engineering students seeking summer or permanent employment. The College of Engineering also provides placement service through its Office of Student Personnel in Carpenter Hall. Information about companies is available at either of these offices, and students may discuss specific employment opportunities and the procedures of job placement with the staff of either office. Another service provided by the Office of Student Personnel in cooperation with the University's placement services is the arrangement of annual interviews between students and prospective employers. Selected engineering faculty members serve as placement advisers with whom students may discuss their career objectives and plans for employment or graduate study.

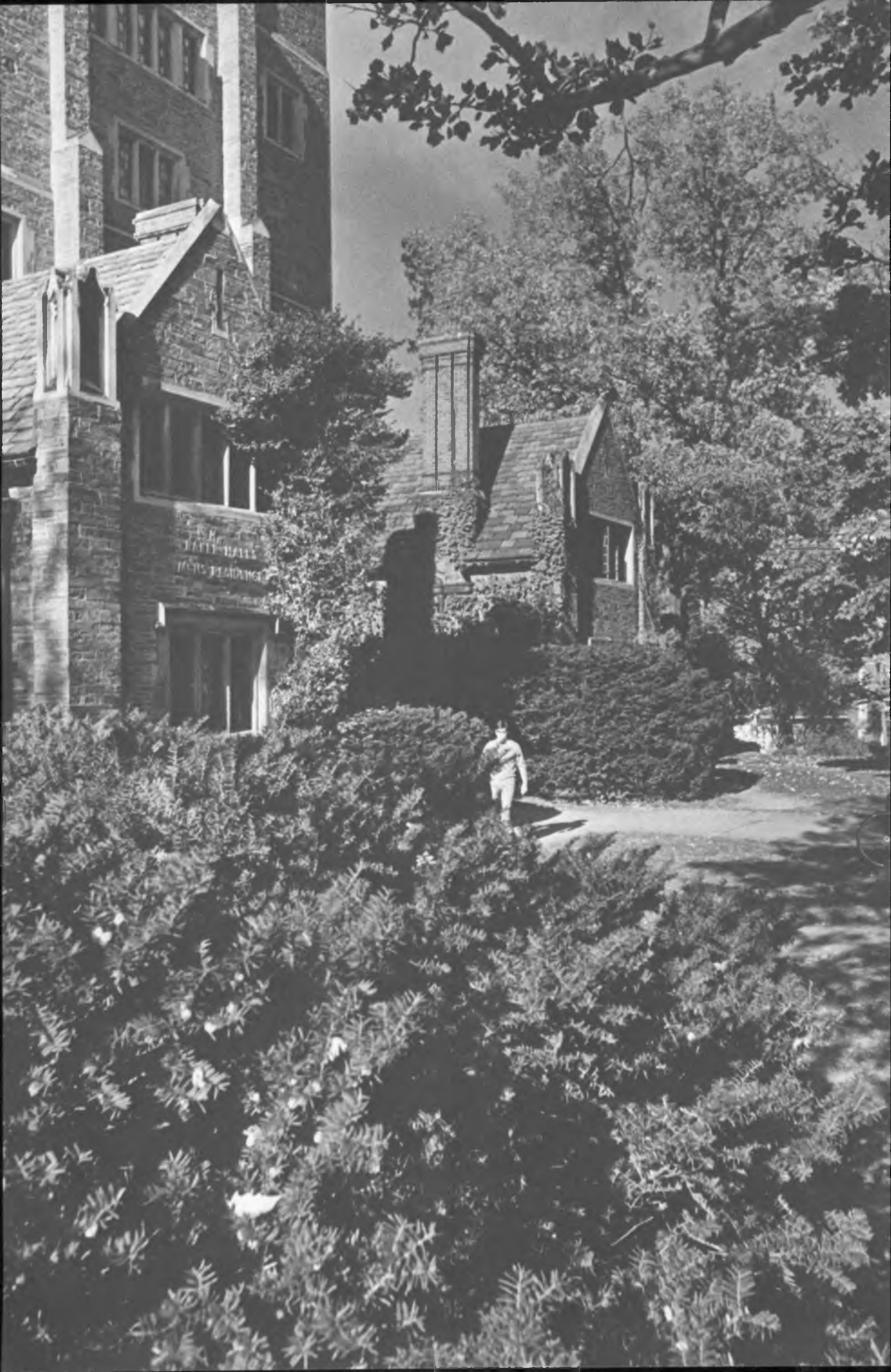
Scholarship Resources

Donor	*Designated Engineering Field*	*Number of Awards (All Classes)*	*Amount per Award*
Alcoa Foundation Scholarship	Any	5	$ 750
Allegheny-Ludlum Achievement Award	Various Specified Fields	3	700
AMF Foundation Scholarship	Mechanical or Electrical Engineering	1	2,000
Charles R. Armington Scholarship	Any	6	2,000 max.
John Henry Barr Scholarship	Any	1	2,000 max.
Seymour L. Baum Memorial Fund	Electrical Engineering	1	200
Robert H. Blackall Scholarship	Any	3	1,250*
Edward P. Burrell Scholarship Endowment	Primarily for Women	10	1,300*
Carrier Memorial Scholarship	Any	3	1,200
Redmond Stephen Colnon Scholarship Endowment	Any	1	1,500
The *Cornell Engineer* Scholarship	Any	1	Variable
Calvin H. and Della N. Crouch Endowment	Mechanical Engineering	1	500
A. Clinton Decker Memorial Scholarship	Any	5	900*
Warren V. Delano Memorial Endowment	Mechanical Engineering	1	450
Otto M. Eidlitz Scholarship Endowment	Any	2	900*
Joseph H. Evans Endowment	Any	1	250
C. Harold Fahy Scholarship Endowment	Civil Engineering	1	700
Elbert Curtiss Fisher Scholarship	Any	1	1,200
Carl R. Gilbert Memorial Endowment	Any	1	350
Emmet Blakeney Gleason Scholarship Fund	Various Specified Fields	1 or more	2,200 max.

* Range variable. Figure given is the mean.

Donor	*Designated Engineering Field*	*Number of Awards (All Classes)*	*Amount per Award*
Paul G. Haviland Memorial Scholarship	Any	1	$1,000
Howard Elmer Hyde Civil Engineering Scholarship	Civil Engineering	1	300
Martin J. Insull Scholarship Endowment	Any	2	1,100*
Albert Jadot Memorial Scholarship Endowment	Foreign Students	1	600
Chester H. Loveland Engineering Scholarship Fund	Civil Engineering	1	1,500 max.
The Charles McAllister '87 Endowment	Any	1	350
Harrison D. McFaddin Scholarship Endowment	Any	4	1,000*
John McMullen Scholarship Fund	Any	500*	2,000*
Minnesota Mining and Manufacturing Company Undergraduate Scholarship	Any	1	1,200
Monsanto Chemical Company Scholarship	Chemical Engineering	1	1,000
Robert C. Newcomb Scholarship Fund	Any	3	950*
Niagara Machine and Tool Works Scholarship	Mechanical Engineering	1	1,000
Frank William Padgham Scholarship Endowment	Mechanical Engineering	1	200
Annie F. and Oscar W. Rhodes Scholarship Endowment	Any	15	1,100*
Huldah Jane Rice Scholarship Endowment	Any	5	1,800*
Rohm and Haas Scholarship	Chemical Engineering	1	1,000
Scott Paper Company Foundation Award	Any	2	1,000
Frederick B. Scott Scholarship Fund	Any	1	1,000
Sylvester Edick Shaw Scholarship Endowment	Any	1	300
Judson N. Smith Scholarship Endowment	Civil Engineering	1	300
Standard Oil of California Scholarship	Mechanical Engineering	1	2,200
Stauffer Chemical Company Scholarship	Chemical Engineering	1	1,000
William Delmore Thompson Scholarship Endowment	Mechanical Engineering	1	100
Universal Oil Products Foundation Scholarship	Various Specified Fields	2	1,000 max.
Leon C. Welch Scholarship Fund	Any	1	800
John L. Wentz Scholarship Endowment	Any	1	400
Western Electric Fund Scholarship	Any	2	1,000
Henry G. White Scholarship	Civil Engineering	1	2,000
Jessel Stuart Whyte Scholarship Endowment	Mechanical Engineering	2	1,500*
Wilson Endowment	Mechanical and Electrical Engineering	1	300
Wyman-Gordon Company Scholarship	Materials Science and Engineering	1	1,000

* Range variable. Figure given is the mean.



Areas of Instruction

Basic Studies

Hollister Hall

Messrs. M. S. Burton, W. H. Bray, C. K. Paul, R. G. Sexsmith.

Courses of instruction are listed on pp. 51–54.

Students in the College of Engineering are enrolled for the first two years of their undergraduate education in the Division of Basic Studies. The Division oversees admissions to the College and administers the program of courses for freshmen and sophomores.

Scholastic Requirements

The Division of Basic Studies of the College of Engineering normally enrolls all students for five courses each term. All of these courses must be passed, with an average of at least 1.7, in order to remain in good standing in the Division. To attain the Dean's Honor List, a student must have a term average of at least 3.25 (see p. 12).

A two-term sequence in engineering subjects (Engineering 105 and 106) is required of all freshmen. Included is instruction in the computer language PL/I; an introduction to engineering design and graphics; and a series of "mini-courses" that focus on different engineering fields and range in activity from projects, field trips, and discussion groups to case studies of engineering-related problems and issues.

During the sophomore year students take four engineering core science courses, selected from offerings in four areas, as outlined on p. 20. Students who are planning to major in chemical engineering as upperclassmen must satisfy special prerequisites, and so substitute these courses for one of the engineering core sciences (see footnote, p. 20). A wise selection of core courses is of considerable importance to the student's subsequent program of studies and should be made in close consultation with a faculty adviser.

A sequence of four courses in mathematics is required of all underclassmen. However, because of advanced placement and credit received upon matriculation, a substantial portion of each class completes this requirement by the end of term 3. All freshmen are enrolled in chemistry during the first term and may take a course in chemistry during the second term if they plan to undertake a chemistry- or materials-related engineering program in their upperclass years. There is also a three-term physics sequence required of all underclassmen. Usually, this sequence begins in term 2, but freshmen with superior mathematics preparation may begin it in term 1. This will enable them to take a fourth course in physics during term 4 if they wish. Students who do not take a second course in chemistry and/or a fourth course in physics may elect any natural or contextually relevant social science course instead. Such electives are in addition to the four liberal studies electives that are offered in the freshman and sophomore years.

All engineering students are required to complete twenty-four hours of liberal studies courses before graduation; twelve hours are normally completed during the underclass years. However, students whose career goals require them to do so may substitute introductory courses in the natural sciences (e.g. biology or organic chemistry) for their liberal studies electives during the sophomore year, and defer these electives until the junior and senior years. The liberal studies electives may include courses in the humanities, social sciences, modern foreign languages, and expressive arts.

All undergraduate students are required by the University to complete four terms of work in physical education. The requirement must be completed within the first four terms unless formal permission for postponement is granted by the Division of Basic Studies. Descriptions of the physical education courses offered will be made available to entering students by the Department of Physical Education and Athletics. For further details, see the *Announcement of General Information*.

A dormitory in the Baker complex on the Cornell campus

Advanced Placement and Honors Sections

Approximately one-fifth of the entering freshman class is normally given advanced placement, which means that these students receive college credit for one or more freshman-year courses on the basis of College Entrance Examination Board advanced placement tests or departmental tests administered during the fall orientation period. It may even be possible for superior students to enroll at the sophomore level by qualifying for two terms of advanced placement in mathematics and in either chemistry or physics, and by completing courses in the other science during the University Summer Session preceding September matriculation.

Especially well prepared students may be enrolled in honors sections of certain freshman courses. Students with superior performance in the freshman year may enroll in sophomore honors sections.

The Curriculum

An outline of courses for the freshman and sophomore years is as follows.

Freshman Year

Term 1	*Hours*
Mathematics 191 or 193, Calculus for Engineers	4
Physics 112, Introductory Analytical Physics	4
or	
Natural or Social Science Elective	3
Chemistry 107, General Chemistry	3
Freshman Engineering Course 105 or 106	3
Liberal Studies Elective	3

Term 2	
Mathematics 192 or 194, Calculus for Engineers	4
Physics 112 or 213, Physics I or II	3 or 4
Chemistry 108, General Chemistry	4
or	
Natural or Social Science Elective	3
Freshman Engineering Course 106 or 105	3
Liberal Studies Elective	3

Sophomore Year

All sophomore engineering students except those planning to major in chemical engineering will take the following program of courses:

Term 3	*Hours*
Mathematics 293 or 293H, Engineering Mathematics	4
Physics 213 or 214, Physics II or III	4
Engineering Core Science Elective*	3
Engineering Core Science Elective	3
Liberal Studies Elective	3

Term 4	*Hours*
Mathematics 294 or 294H, Engineering Mathematics	3
Physics 214, Physics III	4
or	
Natural or Social Science Elective	3
Engineering Core Science Elective	3
Engineering Core Science Elective	3
Liberal Studies Elective	3

* Note: Each upperclass Field Program may specify as a prerequisite one engineering core science from the groups listed below. This course must be successfully completed before a student can enroll in the Field Program at the beginning of his junior year. The following courses will be offered during the academic year 1971–72. Students must complete four of them, choosing a minimum of one course from three of the four groups.

Engineering Core Sciences

Group I	*Hours*
9160, Introductory Probability*	3
9170, Basic Engineering Statistics	3
Computer Science 202, Computers and Programming	3
Group II	
4210, Introduction to Electrical Systems†	3
6262, Electrical Properties of Materials	3
8117, Contemporary Applied Physics	3
Group III	
1021, Mechanics of Solids‡	3
1031, Dynamics	3
6261, Mechanical Properties of Materials	3
1001, Introduction to Applied Mechanics	3
Group IV	
Chemistry 357, Organic Chemistry§	3
Chemistry 358, Organic Chemistry§	3
Chemistry 287, 289, Physical Chemistry§	5
Chemistry 288, 290, Physical Chemistry§	5
3631, Introduction to Thermodynamics	3
5101, Mass and Energy Balances	3

* Required for Industrial Engineering.
† Required for Electrical Engineering or Engineering Physics.
‡ Required for Mechanical Engineering or Civil Engineering.
§ Several courses in physical and organic chemistry offered by the Department of Chemistry in the College of Arts and Sciences at Cornell qualify as engineering core sciences in this area. However, freshmen who are interested in majoring in chemical engineering in their junior and senior years must take Chemistry 287–289, Chemistry 288–290, and Engineering 5101 in their sophomore year as prerequisites; and only two of these three courses may be counted toward the four engineering core sciences required of all sophomores. Students who take these three courses during the sophomore year may be unable to complete the engineering core sciences requirements that year, and so may defer taking the fourth core science until the junior year.

Aerospace Engineering

Grumman Hall

Degrees Offered: Master of Engineering (Aerospace), Master of Science, Doctor of Philosophy.

Mr. E. L. Resler, Jr., director; Messrs. P. L. Auer, P. C. T. deBoer, A. R. George, W. R. Sears, A. R. Seebass, S. F. Shen, D. L. Turcotte.

Courses of instruction are listed on pp. 54–56.

Aerospace engineering deals with problems concerned with the flight of aircraft, guided missiles, and space vehicles in planetary atmospheres and in the regions of space adjoining these atmospheres. The primary objective of the Graduate School of Aerospace Engineering is to educate selected engineering and science graduates in the research and technical aspects of this field. The training is intended primarily to prepare students for research and development engineering in the aerospace industry and in allied research institutions and for university teaching and research.

Superior facilities are provided for laboratory studies in fluid mechanics, aerodynamics, gasdynamics, plasma physics, high-temperature chemical kinetics, laser chemistry, rarefied gas dynamics, magnetohydrodynamics, ferro-fluid dynamics, geophysical fluid mechanics, and other areas. Students and staff also carry out highly theoretical investigations in subjects of their own choice in the aerospace field or in subjects related to the above experimental areas. Emphasis is put on the scientific and engineering aspects of the phenomena encountered by aircraft and space vehicles which leave and reenter planetary atmospheres at extreme speeds. Research work may also be carried out in other related disciplines of interest to the student.

Preparation for Graduate Study

The Graduate School of Aerospace Engineering will consider applicants who hold baccalaureate degrees (or the equivalent) in any branch of engineering, mathematics, or the physical sciences from qualified institutions, provided that their undergraduate scholastic records indicate ability to pursue graduate study successfully. The Cornell programs of study in engineering physics, electrical engineering, and mechanical engineering are especially recommended to undergraduates who expect to enter this School after graduation. The introductory courses Aerospace Engineering 7001 and 7002 would be useful electives.

All students who expect to enter the Graduate School of Aerospace Engineering should try to arrange their undergraduate programs to include as much work as possible in applied mechanics, thermodynamics, mathematical analysis, chemistry, and physics. Suggested courses for engineering students to elect as preparation for graduate work in aerospace engineering include areas of intermediate or advanced physics, such as atomic and molecular physics, kinetic theory of gases, and electricity and magnetism.

The Degree Programs

Master of Engineering (Aerospace)

Undergraduate students who have demonstrated more than average ability, have shown adequate promise for carrying on graduate study, and are interested in extending their education in the aerospace field by training in advanced analytical and research-oriented aerospace subjects are eligible to apply for this program. Candidates for an advanced degree in this field who do not already hold a master's degree are encouraged to matriculate as candidates for the M.Eng. (Aerospace) degree.

The program of aerospace engineering studies is designed to acquaint the student with pioneering engineering work in the aerospace industry, and, beyond that, its objective is to increase the student's facility in the use of the basic sciences in engineering and to stimulate his growth in independent research and development work. Because progress in this field is so rapid, an essential objective of this program is to go beyond the study of present-day practices and techniques and to supply the student with a fundamental background and analytical techniques that will generally prove useful whatever the direction of modern engineering development.

The successful completion of the work for this degree requires that the student pass a series of courses in approved subjects. These include two six-hour sequences in various areas of aerospace engineering. The sequences listed in the table below represent typical ones acceptable for the degree requirements and permit candidates to study in any of five areas of aerospace engineering: (1) fluid mechanics; (2) high-temperature gasdynamics; (3) magnetohydrodynamics; (4) space mechanics; and (5) aerospace structures. Active research in these areas is being carried out in the School. However, the faculty may modify this basic list to suit the needs, interests, and background of individual candidates. Other course sequences leading to specialization in allied fields, such as space power, aerophysics, and chemical kinetics, can be arranged.

Also required are six hours of elective subjects. In addition to those listed below, available elective subjects frequently include courses in their specialties offered by faculty members and visiting staff.

The other requirements for the M.Eng. (Aerospace) degree are six hours of mathematics (1180–81 or 415–16 or the equivalent), attendance at the weekly colloquium (one credit hour per term), and one advanced seminar (two hours) each term. This makes a total of thirty credit hours. Exceptions in rare instances may be made at the discretion of the faculty. Successful completion of the M.Eng. (Aerospace) program is determined by the aerospace faculty, upon review of the student's course record.

Applications for admission should be made to the Office of the Director, Graduate School of Aerospace Engineering, Grumman Hall. A special application blank for this purpose may be obtained from that Office. It is not recommended that candidates apply for admission at midyear, except in very unusual circumstances.

Available Course Sequences for M.Eng. (Aerospace) Degree	*Hours*
7101–02, Applied Thermal Physics, Gasdynamics	6
7201–02, Introductory Plasmadynamics, Introductory Magnetohydrodynamics	6
7301–02, Fluid Mechanics, Aerodynamics	6
1772–73, Space Flight Mechanics, Mechanics of the Solar System	6
2730–31 (1730–31), Transportation Structures I and II	6

*Electives: List A**

7103, Dynamics of Rarefied Gases	3
7104, Advanced Topics in High Temperature Gasdynamics	3
7203, Intermediate Plasma Physics	3
7303, Compressible Fluid Flow	3
7304, Theory of Viscous Flows	3
7305, Hypersonic Flow Theory	3
7306, Atmospheric Motions	3
7307, Acoustics and Aerodynamic Noise	3

Electives: List B

7001, Introduction to Aeronautics	3
7002, Introduction to Aerospace Systems	3
7003, Introduction to Geophysics	3
1126, Foundations of Applied Mathematical Analysis	3
1263, Applied Elasticity	3
1264, Theory of Elasticity	3
1265, Mathematical Theory of Elasticity	3
1362, Vibration of Elastic Systems	4
1370, Intermediate Dynamics	3
1371, Advanced Dynamics	3
1375, Nonlinear Vibrations	3
3652, Combustion Theory	3
3681, Nonequilibrium Flow and Radiative Transfer	3
Physics 443, Atomics and Introductory Quantum Mechanics	4
Physics 444, Nuclear and High-Energy Particle Physics	4
Physics 454, Introductory Solid State Physics	4
Physics 510, Advanced Experimental Physics	3
Physics 561, Theoretical Physics I	4
Physics 562, Theoretical Physics II	4
Physics 572, Quantum Mechanics	4
Physics 574, Intermediate Quantum Mechanics	4
Chemistry 580, Kinetics of Chemical Reactions	4
Chemistry 593, Quantum Mechanics I	4
Chemistry 596, Statistical Mechanics	4
Chemistry 598, Selected Topics in Physical Chemistry	2 or 4
4511, Electrodynamics	4
4531, Quantum Electronics I	4
4532, Quantum Electronics II	4
4561, Introduction to Plasma Physics	3
4562, Waves in Plasmas	3
4661, Kinetic Equations	3

* Basic sequence (01–02) or equivalent is required for registration in elective courses in List A.

Master of Science and Doctor of Philosophy

To do original work in aerospace engineering in its broadest sense requires further advanced study in the Field, plus a thesis. Such study may lead to the degree of Master of Science or Doctor of Philosophy. The student usually works very closely with the faculty members of the School in areas such as basic plasma dynamics, high-temperature chemical reactions, space mechanics problems, fundamental fluid mechanics. The programs are extremely broad in order to accommodate the widest interests of the students and the broadest needs of the industry.

Work is currently under way in many areas. For example, a group is investigating the dynamics of gases at high temperatures. Generally speaking, their interests lie in the application of physics and chemistry to the aerodynamics of propulsion systems, the flight of missiles and space vehicles, and gas laser chemistry.

Magnetohydrodynamics is also a part of the research activities of the Graduate School of Aerospace Engineering. Researchers are exploring the mathematical theory of this phase of fluid mechanics and the higher temperature collisionless regime appropriate to possible fusion applications.

These interests result in close contact between the School and several other divisions of the University, including the Center for Applied Mathematics, the Laboratory of Plasma Studies, and the Center for Radiophysics and Space Research.

Others are pursuing investigations in the areas of rarefied-gas dynamics, hypersonics, basic fluid mechanics, and advanced aerodynamics. The staff is also actively engaged in studies of the sonic boom, aerodynamic noise, and associated problems of high-performance aircraft. The School maintains active interest and research in subjects basic to modern space vehicle and propulsion-system design. Other projects concern geological fluid flows and ferro-hydrodynamics. This brief description is, of course, not all-inclusive and other topics of research are under study.

The School's activities are best summarized through its research work and published papers. Those interested in obtaining copies or abstracts of work recently completed and a brochure entitled *Aerospace Engineering at Cornell* should write to the Director of the School, Grumman Hall.

Agricultural Engineering

Riley-Robb Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Agricultural), Master of Science, Doctor of Philosophy.

Mr. O. C. French, director; Messrs. R. D. Black, J. R. Cooke, R. B. Furry, W. W. Gunkel, D. A. Haith, W. L. Hewitt, G. Levine, R. C. Loehr, H. A. Longhouse, R. T. Lorenzen, D. C. Ludington, W.

F. Millier, G. E. Rehkugler, N. R. Scott, E. S. Shepardson, J. W. Spencer.

Courses of instruction are listed on pp. 56–57.

A joint program administered by the Colleges of Agriculture and Engineering leads to the degree of Bachelor of Science. Students in this curriculum register in the College of Agriculture during the first three years but take courses in the Colleges of Engineering, Arts and Sciences, and Agriculture. They register in the fourth and final year for a College Program in the College of Engineering, which grants the degree.

The purpose of this curriculum is to prepare engineers for a career in one of the many industries and agencies that supply the great variety of products, machines, and services required by commercial farms or those who process, handle, and distribute the products of farms. More specialized study is offered in the various graduate degree programs.

Laboratory and Research Facilities

Riley-Robb Hall, on the College of Agriculture campus, provides excellent classroom and laboratory facilities for both teaching and research. Major items of laboratory equipment include electric dynamometers, universal testing machines, fluid flow demonstration and metering equipment, strain measurement instruments, digital recording equipment, an electronic analog computer, torque meters, high speed camera and film analysis equipment, modern farm machines, power units and materials handling equipment, soil properties and moisture determination apparatus, and complete machine shop facilities.

Laboratory equipment and space in Riley-Robb Hall permit investigation of many aspects of agricultural waste management, including liquid and solid waste handling, treatment and disposal, and odor control. A separate waste treatment laboratory is used for waste management pilot plant studies.

The Department has an extensive research program supported through the Cornell Agricultural Experiment Station. This also serves to provide many students with opportunities for part-time work during the academic year and for summer employment.

The Degree Programs

Bachelor of Science

The program for the underclass years is as follows.

Term 1	*Hours*
Mathematics 191, Calculus for Engineers	4
Chemistry 103, Introduction to Chemistry	3
or	
Chemistry 107, General Chemistry	3
or	
Chemistry 115, General Chemistry and Inorganic Qualitative Analysis	4
Agricultural Engineering 153, Engineering Drawing	3
Biological Science 101 or 107	3
Liberal Studies Elective	3
Term 2	
Mathematics 192, Calculus for Engineers	4
Physics 112	4
Agricultural Engineering 152, Introduction to Agricultural Engineering Measurements	3
Biological Science 103 or 108	3
Liberal Studies Elective	3
Term 3	
Mathematics 293, Engineering Mathematics	4
Physics 213	4
Engineering 1001, Introduction to Applied Mechanics	3
Engineering Science	3
Liberal Studies Elective	3
Term 4	
Mathematics 294, Engineering Mathematics	3
Physics 214	4
Engineering Science	3
Engineering Science	3
Liberal Studies Elective	3

In addition to these courses, all freshmen and sophomores must satisfy the University's requirements in physical education.

The curriculum for terms 5 to 8 consists of:

1. A structured program of at least forty-two credit hours including *(a)* a minimum of thirty hours of engineering courses including at least eleven hours of agricultural engineering courses at the 450 level or higher; and *(b)* a minimum of twelve hours of biological sciences and/or agriculture electives.

2. Additional free elective and other courses designed to provide depth in the student's major areas of interest, as well as to satisfy the requirements for ninety hours of courses in the core curriculum and a total of at least 126 hours (as required by the College of Engineering). A complete description of the courses in agriculture may be found in the *Announcement of the College of Agriculture.*

Specialization in agricultural engineering does not require the period of practice before graduation that is required for specialization in some areas of agricultural study. However, appropriate summer work experience is encouraged, and faculty advisers will assist their advisees in obtaining suitable jobs.

To remain in good standing in the agricultural engineering program, a student must attain each term a weighted average of at least 1.7 (see p. 12).

Agricultural Engineering Minor (College Program). College Program students interested in the application of engineering to plant and animal systems may elect an agricultural engineering minor which has the following requirements: (1) a minimum of six hours of agricultural engineering courses at the 400 level or above; (2) a minimum of six hours of biological science and/or agriculture courses beyond the introductory biological science sequence; and (3) a minimum of six hours of engineering courses related to the student's interest in agricultural engineering. These courses are selected by the student in consultation with his faculty adviser for the minor.

Master of Engineering (Agricultural)

The degree of Master of Engineering (Agricultural) is available as a curriculum type of professional degree, intended primarily for those students who plan to enter engineering practice and not for those who expect to study for the doctorate. This program consists of courses which are intended to develop the student's background in engineering design as well as to strengthen his fundamental engineering base. Six hours of the required thirty hours consist of engineering design experience involving individual effort and a formal report. Admission to the M.Eng. (Agricultural) program is open to persons who have been granted Bachelor's degrees or the equivalent and who have sufficient training to indicate that they can profitably study the advanced courses offered in the program. A student can choose to concentrate his studies 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, and *(e)* agricultural waste management.

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, sanitary engineering, soil engineering, and waste management.

Master of Science and Doctor of Philosophy

Flexible programs leading to the Ph.D. degree are offered in the following areas of specialization: agricultural engineering, agricultural structures, power and machinery, soil and water engineering, electric power and processing, and agricultural waste management. Two minor subjects, at least one of which must be in an engineering, agricultural, or basic science subject outside the Field, are also selected. Candidates for the M.S. degree take agricultural engineering as their major subject and select one minor from outside the Field.

A broad and active research program, supported by the Cornell Agricultural Experiment Station, gives the graduate student an opportunity to select a challenging research project for his thesis. Assistantships and traineeships are available, and provide annual stipends comparable to those offered at other land grant institutions.

More detailed information, along with application forms and other descriptive information pertinent to M.S. and Ph.D. programs in this Field, may be obtained by writing to the Office of the Graduate Field Representative, Riley-Robb Hall. A brochure entitled *Agricultural Engineering at Cornell* may also be obtained from this office.

Applied and Engineering Physics

Clark Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Engineering Physics), Master of Science, Doctor of Philosophy.

Mr. J. Silcox, director; Mr. P. L. Hartman, associate director; Messrs. B. W. Batterman, K. B. Cady, D. D. Clark, R. K. Clayton, D. R. Corson, T. R. Cuykendall, H. H. Fleischmann, V. O. Kostroun, J. A. Krumhansl, A. Kuckes, R. L. Liboff, R. McPherson, M. S. Nelkin, E. L. Resler, Jr., T. N. Rhodin, N. Rostoker, H. S. Sack; Mrs. M. M. Salpeter; Messrs. B. M. Siegel, R. N. Sudan, W. W. Webb, G. J. Wolga.

Courses of instruction are listed on pp. 57–60.

Creativity and innovation in engineering and applied science require a thorough knowledge of physics and applied mathematics, and of the techniques for applying this knowledge. The degree programs of the School of Applied and Engineering Physics are designed to provide the opportunity to achieve proficiency in these areas. They are particularly suitable for students who wish to prepare for careers in fields of applied science which are based on principles and techniques of physics and in associated areas of physics.

Research and Laboratory Facilities

The School of Applied and Engineering Physics is centered in Clark Hall, which houses the University's physical sciences library, research laboratories and offices for solid state and surface physics, the Materials Science Center, and technical and other supporting services. Facilities of other University laboratories and centers are also available for research in applied and engineering physics. These include the Center for Radiophysics and Space Research, the Ward Laboratory of Nuclear Engineering, the Laboratory of Plasma Studies, and facilities of the Division of Biological Sciences and of other schools and departments in the College of Engineering.

The Degree Programs

Bachelor of Science

To choose engineering physics as an undergraduate major is to choose an approach rather than a professional career specialty; the majority of students go on to graduate study in a wide variety of fields. The program includes a core of courses in basic physics and applied mathematics, but is flexible enough to permit the development of a coherent program in any of a number of areas, including some outside of physics.

A major emphasis throughout the course of study is the development of insight into the application of concepts. This, combined with the basic studies, provides a background for later work in applied science. Research projects in areas in which faculty members are active may be undertaken during the senior year. These areas include electron microscopy and diffraction, quantum electronics, solid state and surface physics, low-energy nuclear physics, nuclear chemistry, and nuclear reactor physics and technology. (Current areas of research are described in detail in the section below on the Master of Science and Doctor of Philosophy degree programs.) Students may also participate in the University's plasma physics program.

Areas of graduate study for which engineering physics is a suitable undergraduate background include: aerospace engineering, applied mathematics, applied physics, astrophysics, atmospheric sciences, biophysics, energy conversion, environmental science, geophysics, materials science, nuclear engineering, nuclear physics, oceanography, plasma physics, quantum optics, solid state electronics and physics, and space sciences. In many of these areas there are no directly related undergraduate courses, and preparation for their study depends upon an appropriate choice of undergraduate electives. The choice of electives should be discussed with an engineering physics faculty member as early as possible during the undergraduate years.

Students in the engineering physics program may also qualify for the professional Master of Engineering programs in engineering physics, nuclear engineering, or aerospace engineering, or for further education in other professional fields that are enriched by a background in applied science. Positions in industry, often entailing on-the-job or advanced training programs, may also be considered by engineering physics graduates.

The first two years of the undergraduate program are administered by the Division of Basic Studies (see pp. 19–20). Since considerable interest and proficiency in physics and mathematics are required for a major in engineering physics, students who intend to enter this upperclass field program are advised to register in honors sections of physics and mathematics during the underclass years.

Of the core engineering sciences that may be completed before the end of the sophomore year, the course Introduction to Electrical Systems (4210) is required, and the course Contemporary Topics in Applied Physics (8117) is strongly recommended. Students planning to major in engineering physics should consult with a member of the School's faculty for assistance in choosing other courses in the sophomore year.

The following curriculum, or its equivalent, constitutes the upperclass Field Program.

Term 5	*Hours*
Mathematics 421, Applicable Mathematics	4
8155, Intermediate Electromagnetism	3
8133, Mechanics of Particles and Solid Bodies	3
Free Elective*	3 or 4
Liberal Studies Elective	3 or 4
Term 6	
Mathematics 422, Applicable Mathematics	4
8156, Intermediate Electrodynamics	3
8161, Introductory Quantum Mechanics	4
Free Elective*	3 or 4
Liberal Studies Elective	3 or 4
Term 7	
Mathematics 423, Applicable Mathematics	4
8123, Statistical Thermodynamics	3
Physics 410, Advanced Experimental Physics	4
Technical Elective*	3 or 4
Liberal Studies Elective	3 or 4
Term 8	
8124, Statistical Physics	3
8134, Mechanics of Continua	3
Applications of Quantum Mechanics†	3 or 4
Technical Elective*	3 or 4
Liberal Studies Elective	3 or 4

* The electives need not all be formal course work; qualified students may undertake informal study under the direction of a member of the faculty.

† A choice of the following courses may be made: Physics 454, Introductory Solid State Physics; Physics 444, Nuclear and High-Energy Particle Physics; Engineering 8309, Low-Energy Nuclear Physics; Engineering 8501, Physics of Atomic and Molecular Processes; Engineering 4351, Quantum Electronics I (fall term).

Considerable flexibility is possible in the scheduling of these courses during the four terms. For example, Physics 410 may be taken in either term 7 or term 8. Quantum mechanics can be studied in term 6 as Engineering 8161 or in term 7 as Physics 443. The applications of quantum mechanics course can be taken whenever the appropriate prerequisite has been met.

A student with a coherent program in an area outside of physics may petition to omit 8134 and/or 8124 in his eighth term.

The engineering physics student is expected to pass every course for which he is registered, to attain each term a grade point average of at least 2.3 (see p. 12), and to demonstrate aptitude and competence in the basic subject matter of the curriculum.

The College Program. Students who elect to develop a College Program (see p. 31) may choose a major from an area of applied physics. Examples are given below.

Major in Engineering Physics
8155, Intermediate Electromagnetism
8156, Intermediate Electrodynamics
8161, Introductory Quantum Mechanics
Physics 410, Advanced Experimental Physics

Major in Nuclear Engineering
8301, Nuclear Energy and the Environment
8303, Introduction to Nuclear Science and Engineering
Two of the following courses:
8312, Nuclear Reactor Theory I
8351, Nuclear Measurements Laboratory
8333, Nuclear Reactor Engineering
8309, Low-Energy Nuclear Physics

Also available is a College Program in Energy Conversion, a synthesis of nuclear, thermal, and electrical engineering studies. This program is described on p. 33.

Master of Engineering (Engineering Physics)

The primary objective of the fifth year of study in engineering physics is to provide an opportunity for advanced study at the professional level; students who earn the M.Eng. (Engineering Physics) degree may move into development or research in industrial or governmental institutions. The program may also serve as a preparation for more advanced graduate study in applied physics, or as exploratory study for the student interested in starting graduate work but not ready to make a commitment to a specific field. Finally, it provides an opportunity to satisfy prerequisite course work in certain new areas of graduate study which involve a combination of engineering or applied physics with another professional but nontechnical discipline.

The degree requirements permit considerable flexibility in the course program, which is planned by the student in consultation with the program chairman. The following academic components are required:

1. An informal study or project, experimental or analytical, which requires individual effort and is completed with a formal report. This carries at least six hours of credit. It is usually completed by the end of the second semester but permission to continue through the summer may be obtained. If the project is experimental, one course in mathematics or applied mathematics at the graduate level is required; if the project is analytical one term in experimental laboratory physics at the graduate level or its equivalent must be taken. The study or project is chosen in consultation with the chairman of the program and is carried out under the personal direction of an appropriate member of the engineering or science faculty.

2. A graduate level course in quantum mechanics or its equivalent upon approval of the chairman of the program. (Such a course need not be repeated if it has been completed during the undergraduate program.)

3. A fourth year or graduate level course in statistical mechanics or, with approval of the chairman of the program, a course of a related nature. (Such a course need not be repeated if it has been completed during the undergraduate program.)

4. Attendance at a sequence of approximately thirteen scheduled University seminars or colloquia chosen in consultation with the chairman of the program.

5. Electives in the area of technology and applied science, including a minimum of six credit hours in a graduate-level course sequence.

6. A total of thirty semester hours credit beyond the Bachelor's degree.

The qualified student may earn credit through informal study under the personal direction of a faculty member or may take courses that are preparatory for entrance into a new graduate field.

Admission to the M.Eng. (Engineering Physics) program is extended to Cornell baccalaureate graduates in engineering physics who had a grade-point average of at least 2.5 (see p. 12) for the four-year course of study. If the student's average is lower than 2.5, he must petition for admission. All other applicants must provide evidence of undergraduate preparation adequate for the demands of the program. In addition to a transcript, two letters of recommendation and a statement of academic purpose are required of non-Cornell students.

Application forms for admission to the program and for financial aid can be obtained at the office of the School of Applied and Engineering Physics, Clark Hall. Financial assistance in amounts up to full coverage of tuition and fees (depending on merit and need) and guaranteed loan support are available. It is recommended that both applications be submitted prior to February 1. All applicants will be notified with reference to both admission and aid by April 1, and should notify the School of their decisions by May 1.

Inquiries about the study program, available facilities, admission requirements, or financial aid should be addressed to the Program Chairman, Master of Engineering (Engineering Physics), Clark Hall.

Master of Engineering (Nuclear)

A Cornell student who completes the undergraduate engineering physics curriculum with a 2.3 or higher grade-point average (see p. 12) can be admitted without petition to the Master of Engineering (Nuclear) program. This program is described under the Nuclear Science and Engineering section of the *Announcement* (see p. 45).

Master of Science and Doctor of Philosophy

The graduate program in the Field of Applied Physics provides a means for students with undergraduate training in physics to branch out into applied science while continuing the study of physics and for students with backgrounds in engineering or another science to extend their knowledge of physical science principles and techniques. A student may choose for specialization and thesis research any subject that involves the application of principles of physics and mathematics. The formal course programs leading to the M.S. and Ph.D. degrees contain a core of physics and mathematics courses, but individual programs of study are designed to meet the needs and interests of each student. Programs involving several academic disciplines and topics that are undergoing transition from fundamental physics to applied physics are readily accommodated.

Current areas of advanced study and research include: applied theoretical physics, biophysics, chemical physics, physics of fluids, nuclear and reactor physics, optics, plasma physics, radiation and matter, solid state physics and materials sciences, space physics, and surface physics. Specific research projects in which graduate students in applied physics are currently participating include studies of coherence of light generated by lasers, superconductivity in high magnetic fields, phase transformations at high pressures, high resolution electron optics, studies of quantum electronics using infra-red spectroscopy, observations of critical phenomena in fluids using homodyne spectroscopy, observations of the atomic structure of crystal surfaces by field ion microscopy and low energy electron diffraction, analysis of nuclear structure by analysis of the decay of short-lived radio isotopes formed in a pulsed nuclear reactor, theoretical studies of plasma instabilities, molecular dynamics in fluids, the statistical physics of phase transitions in quantum fluids, and experimental studies of atomic collisions.

Details of the program, requirements for admission, and areas of advanced study are given in the *Announcement of the Graduate School* and in a brochure available from the Office of the Field Representative, Applied Physics, Clark Hall.

Chemical Engineering

Olin Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Chemical), Master of Science, Doctor of Philosophy.

Mr. K. B. Bischoff, director; Messrs. J. L. Anderson, G. G. Cocks, V. H. Edwards, R. K. Finn, P. Harriott, J. E. Hedrick, F. Rodriguez, G. F. Scheele, J. C. Smith, J. F. Stevenson, R. G. Thorpe, R. L. Von Berg, H. F. Wiegandt, C. C. Winding, R. York.

Courses of instruction are listed on pp. 60–63.

Chemical engineering involves the application of the principles of the physical sciences and mathematics and of engineering judgment to fields in which matter is treated to effect a change in state, energy content, or chemical composition. Many chemical engineers are employed in the process industries. In these industries, raw materials are converted to useful products such as industrial chemicals, petroleum products, metals, rubbers, plastics, synthetic fibers, foods, paints, and paper. Because of their knowledge of chemistry, chemical engineers are also prepared to serve in related fields such as biochemical and biomedical engineering, nonmetallic materials, waste disposal, and pollution abatement.

An integrated program in chemical engineering leads to a Bachelor of Science degree at the end of four years and to a Master of Engineering degree in one additional year. The curriculum applies the latest developments in the fields of chemistry, mathematics, physics, and the engineering sciences to chemical engineering concepts and provides enough flexibility so that students may prepare themselves for the broad application of these concepts to many engineering problems. A four-year sequence of liberal studies electives provides an opportunity to attain a background in the social sciences, economics, or other nontechnical subjects. Free electives in the upperclass years permit the choice of additional courses in such fields. Free and technical electives may be used to broaden the student's preparation in the sciences and engineering or to study specialties in more depth. The School of Chemical Engineering offers special programs in biological engineering, polymeric materials, chemical microscopy, and process control. Students may also use their electives to attain greater proficiency in fields such as chemistry, mathematics, environmental systems engineering, water resources, computer science, or nuclear engineering.

Laboratory and Research Facilities

All Cornell programs in chemical engineering, both undergraduate and graduate, are given in Olin Hall of Chemical Engineering. This modern and well-equipped building, with over 100,000 square feet of floor space, provides lecture and recitation rooms as well as laboratories for instruction and research. The main laboratory extends through three floors and contains pilot-plant equipment for undergraduate projects and research as well as space for research apparatus for graduate students. Shops, storage, and service facilities are adjacent to this laboratory.

In addition, a large portion of the building is devoted to small-unit laboratories containing furniture and equipment suitable for the chemical and bench-scale projects and research carried out by both undergraduate and graduate students. Specialized laboratories are also available. The Geer Laboratory for Rubber and Plastics has facilities for making, processing, and testing all types of polymeric materials. The biochemical engineering laboratory contains equipment for fermentation and other biochemical processes; the process control area is equipped with control instruments, recorders, and computers.

The Degree Programs

Bachelor of Science

The Field Program in Chemical Engineering offers a coordinated sequence of chemical engineering courses beginning in the sophomore year and extending through the fourth year.

Course programs for terms 1 through 4, administered by the Division of Basic Studies, are described on pp. 19–20. While enrolled in the Division of Basic Studies, the student planning to enter the professional chemical engineering program registers for Chemistry 287–288, Chemistry 289–290, and Engineering 5101 during the sophomore year.

The program for the upperclass years is as follows.

Term 5	*Hours*
Chemistry 357, Organic Chemistry	3
5102, Equilibria and Staged Operations	3
5257, Materials*	5
Elective†	3
Liberal Studies Elective	3
Term 6	
Chemistry 358, Organic Chemistry	3
Chemistry 355, Organic Chemistry Laboratory	2
5304, Introduction to Rate Processes	3
5103, Chemical Engineering Thermodynamics	3
Elective†	3
Liberal Studies Elective	3
Term 7	
5305, Analysis of Separation Processes	3
5353, Chemical Engineering Laboratory	3
5623, Chemical Process Evaluation	4
Elective†	3
Liberal Studies Elective	3
Term 8	
5106, Reaction Kinetics and Reactor Design	3
5624, Chemical Process Synthesis*	4
Electives†	6
Liberal Studies Elective	3
5041, Nonresident Lectures	0

* Students who have an approved plan for concentration in a minor topical area and who require more elective courses than the number scheduled to accomplish their goals may substitute additional electives for Engineering 5257, Materials (provided that 6261, Mechanical Properties of Materials, has been chosen as an engineering core science during the sophomore year) and/or 5624, Chemical Process Synthesis. This option could be of interest to students planning concentrations in such areas as biological engineering, environmental studies, advanced chemistry, and systems and operations research.

† The electives must include the postponed engineering core science course (see the section on Basic Studies).

The College Program. Students pursuing a four-year College Program, described on p. 31, may elect a major or a minor in chemical engineering. These majors and minors require a sequence of chemical engineering courses in the third and fourth years, plus the proper prerequisites, as specified by the student's adviser and the College Program Committee.

Predoctoral Honors Program. The Predoctoral Honors Program is available to capable undergraduates who intend to seek a doctorate. Under this program, it is possible to complete the requirements for the Ph.D. degree in three academic years and a summer after receipt of the Bachelor's degree.

Qualified undergraduates interested in this program may apply for admission during their third year. Evidence of initiative and research ability is required and is considered to be just as important as scholastic standing. Admission to this program must be approved by the faculty of the School, and a student's progress is reviewed at the end of each term.

During his fourth year, a student in this program begins, as a project-laboratory course, a research project which may be continued through the fifth year to meet the thesis requirement for the M.S. degree. This degree is awarded at the end of the fifth year. All the course work required for the Ph.D. degree should be completed by the end of the sixth year, and the student should have enough research experience to select and complete a Ph.D. thesis during the following fifteen months.

Master of Engineering (Chemical), Master of Science, and Doctor of Philosophy

A student holding a baccalaureate or equivalent degree in chemical engineering from a college of recognized standing is eligible to pursue advanced work leading to a professional degree, Master of Engineering (Chemical), or to the general degrees, M.S. or Ph.D., with majors in chemical engineering.

The professional Master's degree, M.Eng. (Chemical), is awarded for the successful completion of the five-year program in chemical engineering at Cornell. Graduates who hold a baccalaureate degree in chemical engineering are awarded this degree at the end of one year of study if they successfully complete thirty credit hours of required and elective courses in technical fields including engineering, mathematics, chemistry, physics, and biology. Courses emphasize design and optimization based on the economic factors that affect process, equipment, and plant design alternatives. No thesis is required, but a design project is involved in the required courses.

The M.S. and Ph.D. degrees are administered by the Graduate School and require work in both major and minor fields of study, as well as the completion of a thesis involving individual experimental research or analytical investigations. A student interested in these degrees should consult the *Announcement of the Graduate School.* A brochure entitled *Chemical Engineering at Cornell* describes the various areas of specialization and research interests of the faculty. It may be obtained by writing to the Graduate Field Representative, School of Chemical Engineering, Olin Hall.

Civil and Environmental Engineering

Hollister Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Civil), Master of Science, Doctor of Philosophy.

Mr. W. R. Lynn, director; Mr. W. L. Hewitt, assistant director; Messrs. V. C. Behn, D. J. Belcher, P. L. Bereano, W. H. Bray, W. Brutsaert, L. B. Dworsky, L. M. Falkson, G. P. Fisher, R. H. Gallagher, C. D. Gates, P. Gergely, D. A. Haith, A. Wm. Lawrence, T. Liang, J. A. Liggett, R. C. Loehr, D. P. Loucks, G. B. Lyon, W. McGuire, A. J. McNair, A. H. Meyburg, A. H. Nilson, C. K. Paul, T. Peköz, D. A. Sangrey, R. G. Sexsmith, F. O. Slate, S. Stidham, Jr., P. R. Stopher, H. M. Taylor, 3d, R. N. White, G. Winter. Visiting staff: Mr. C. R. Glassey.

Courses of instruction are listed on pp. 63–71.

Civil and environmental engineering deals primarily with the large fixed works, systems, and facilities that are basic to community living, industry, and commerce and vital to man's well-being. The planning, design, construction and operation of transportation systems, bridges, buildings, water and sewage treatment facilities, dams, and other major artifacts of society are civil and environmental engineering activities. Civil and environmental engineers are major contributors to the solution of problems of urbanization, city planning, and environmental quality control. A burgeoning national population and the desire of people to cluster in city complexes require a great increase in the number of well-prepared engineers who can meet the basic needs of society with efficiency, economy, and safety.

The wide range of subjects which are the concerns of civil and environmental engineers are generally grouped into a number of sub-fields and specializations. At Cornell, there are two subject departments in the School of Civil and Environmental Engineering: Structural Engineering (see p. 30) and Environmental Engineering (see p. 30). Within the department of Environmental Engineering, there are three major areas: environmental protection and management, geophysical engineering, and public systems planning and analysis.

These departments provide courses for graduate study leading to advanced degrees and also those courses necessary to support the undergraduate curriculum in civil and environmental engineering. The specific aims, objectives, and programs of the above departments are described under the subject names of the departments on the pages listed above.

The Degree Programs

The undergraduate field curriculum in civil and environmental engineering leads to the degree Bachelor of Science. It provides a thorough foundation in the basic sciences, applied sciences, and mathematics which are fundamental to the profession. It also includes an introduction to the major areas of modern civil and environmental engineering technology and substantial opportunity for liberal study.

Most students go on to graduate study after completion of the baccalaureate. The three main paths of advanced work at Cornell are:

1. Graduate study in the Field of Civil and Environmental Engineering leading to the degree of Master of Engineering (Civil). This is the first degree with a civil engineering designation. It is obtained upon completion of a curricular program of thirty credit hours of advanced study, including an extensive design project. The M.Eng. (Civil) program is designed primarily for students who intend to enter the professional practice of engineering, and the degree represents attainment of an educational level considered essential for modern practice.

2. Graduate study leading to the degrees Master of Science and Doctor of Philosophy. These degrees are intended primarily for students who plan careers in research, development, or teaching in an area of civil and environmental engineering.

3. Advanced study in a related technical field such as applied mechanics, aerospace engineering, or urban planning, or in a non-technical field requiring an engineering background, such as law or business administration.

Bachelor of Science

The first four terms are described on p. 20 of this *Announcement.* The Division of Basic Studies program specifies that two engineering core science courses be taken in each term of the sophomore year. Mechanics of Solids 1021 is required for entry into the Civil and Environmental Engineering Field Program. It is recommended, but not required, that students planning to enter this Field take Basic Engineering Statistics (9170) and Dynamics (1031) or Mechanical Properties of Materials (6261) as two of their other sophomore engineering core science courses.

The following recommended sequence of courses is intended 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. Students with a well-defined special interest may choose to depart from this sequence. In such cases, a special program should be developed by the student in consultation with a faculty adviser of his choice within the Field, preferably prior to the fifth semester, and submitted to the Field Curriculum Committee for approval. It is advisable for a student to submit an application for a special program as early as the first term of his sophomore year.

Term 5	*Hours*
1031, Dynamics*	3
2301, Fluid Mechanics	3
2701, Structural Engineering I	3

Term 5 [continued]	*Hours*
9170, Probability and Statistics*	3
Liberal Studies Elective	3
Term 6	
6261, Mechanical Properties of Materials*	3
2501, Environmental Quality Engineering	3
2401, Soil Mechanics	3
2603, Engineering Economics and Systems Analysis	3
Liberal Studies Elective	3
Term 7	
Civil and Environmental Engineering Electives (2)†	6
Technical Elective	3
Free Elective	3
Liberal Studies Elective	3
Term 8	
Civil and Environmental Engineering Electives (2)†	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.
† There are distribution requirements on the four civil and environmental engineering electives. The student may obtain information on these requirements from his faculty adviser.

The College Program. As an alternative to the Field Program, a student with a strong interest in an interdisciplinary specialized program may wish to consider the College Program (see p. 31). Where this involves one of the areas of civil and environmental engineering, either as a major or minor subject, the various department faculty members are prepared to advise and assist the student upon request. Examples of College Programs are those combining study in structural engineering and architecture, transportation engineering and urban planning, environmental systems engineering and operations research, sanitary engineering and oceanography, and public systems planning and analysis (see p. 33).

Master of Engineering (Civil)

This degree is available as a curricular type of professional degree, the general requirements for which are stated on p. 14. The basic School requirement is satisfactory completion of at least thirty credit hours of approved course work beyond the Cornell four-year program or its equivalent in the Field of Civil and Environmental Engineering. A substantial portion of the work may be in one of the areas of concentration within civil and environmental engineering. At least six credit hours in the areas of law, management, or economics are required. Also required as part of the total is satisfactory completion of a graduate-level civil engineering project of three to eight credit hours. Projects are designed to include the following aspects of engineering: feasibility study, analysis, design, economics, and systems analysis. Normally, the project requirement is met through the two-course sequence Engineering 2010–2011.

Master of Science and Doctor of Philosophy

The requirements for the degrees of Master of Science and Doctor of Philosophy are described in the *Announcement of the Graduate School: Physical Sciences.* These are degrees oriented toward research and require submission of a thesis.

In the Field of Civil and Environmental Engineering a number of special areas of concentration are available as either major or minor subjects. These concentrations are identified with the departments of Structural Engineering and Environmental Engineering, which provide related graduate instruction.

A number of fellowships and assistantships are available to graduate students in civil and environmental engineering. Prospective graduate students should consult the *Announcement of the Graduate School.* A brochure entitled *Civil Engineering at Cornell,* may be obtained by writing to the Office of the Graduate Field Representative, Civil and Environmental Engineering, Hollister Hall.

Department of Structural Engineering

Mr. R. H. Gallagher, chairman; Messrs. P. Gergely, W. McGuire, A. H. Nilson, T. Peköz, D. A. Sangrey, R. G. Sexsmith, F. O. Slate, R. N. White, G. Winter.

Structural engineering comprises the analysis and design of structures of all types, those traditionally identified with civil engineering (e.g., buildings, bridges, watertanks, and dams) as well as those connected with other branches of engineering (e.g., aerospace structures, pressure vessels, and nuclear engineering structures). The Department of Structural Engineering is responsible for undergraduate and graduate instruction and for research in all these areas. In addition, instruction and research in civil engineering structural materials (e.g., concretes, asphalts, and structural metals) are also the Department's responsibility.

Instruction, both undergraduate and graduate, emphasizes fundamental understanding of structural behavior and modern methods of design and analysis, many of them computer-oriented. A large volume of research, sponsored by government agencies and industry, is carried out in three large and fully equipped laboratories: a structural laboratory for full-scale testing, an extensively equipped models laboratory, and a versatile cement and concrete laboratory.

Department of Environmental Engineering

Mr. W. R. Lynn, chairman; Messrs. V. C. Behn, D. J. Belcher, P. L. Bereano, W. H. Brutsaert, L. B. Dworsky, L. M. Falkson, G. P. Fisher, C. D. Gates, D. A. Haith, W. L. Hewitt, A. Wm. Lawrence,

T. Liang, J. A. Liggett, R. C. Loehr, D. P. Loucks, G. B. Lyon, A. J. McNair, A. H. Meyburg, D. A. Sangrey, S. Stidham, Jr., P. R. Stopher, H. M. Taylor, 3d. Visiting staff: Mr. C. R. Glassey.

Environmental engineering is concerned with a large number of interrelated problem areas: the physical, biological, chemical, and social phenomena which characterize the environment; design and development of technological innovations to protect and improve the quality of the environment; and planning, analysis, and assessment of technical and economic alternatives for control of environmental quality. Because of the broad scope of environmental engineering and in order to identify special instructional and research capabilities, the Department of Environmental Engineering is divided into three areas: *Environmental Protection and Management, Geophysical Engineering,* and *Public Systems Planning and Analysis.* Faculty members in the Department are frequently active in more than one of these areas.

Environmental Protection and Management

Environmental protection and management is concerned with the phenomena, concepts, methods, and technology essential to maintaining the natural environmental quality at levels beneficial to man. This subject area focuses on the protection and management of air, land, and water resources, on water residuals management, and on environmental quality control. Instruction and research concentrate, first, on the pertinent biological, chemical, physical, and engineering principles and phenomena, and, second, on the use of this knowledge in the planning, design, and management of the processes, systems, facilities, and policies needed to achieve societal environmental quality objectives.

The environmental engineering facilities are housed in approximately 6,300 square feet of laboratory space and controlled-temperature rooms, including water microbiology and water chemistry laboratories, as well as rooms specially equipped for bench and pilot-level unit process studies.

Geophysical Engineering

Geophysical engineering is concerned with those aspects of civil and environmental engineering which are associated with the use of the surface of the earth. Earth measurement is an important part and involves surveying, geodesy, photogrammetry, and the related computing and data presentation methods. The techniques of interpretation of aerial photographs and other remote sensing devices, coupled with ground observations, are used to establish the overall nature of the environment and to define problems and aid in their solutions. Soil mechanics and foundation engineering are concerned with the measurement of soil and rock properties and their use in the design process. Fluid mechanics and the associated applications to hydraulics-hydrology and to oceanography are pertinent to study of the wet earth and atmosphere.

Well-equipped laboratories are used for both instruction and research. In the photogrammetric area, a three-projector stereo plotter, and a number of other instruments are available. A large collection of aerial photographs from all over the world is used in both photogrammetric and aerial photographic studies. A large variety of geodetic instruments is available. The soil mechanics laboratories contain a wide variety of both standard and specialized soil testing equipment. Excellent facilities for the testing of stabilized soils and asphaltic mixtures are provided. The hydraulics laboratory is equipped for demonstrations in wave mechanics and rotating flows and for a variety of conventional experiments.

Public Systems Planning and Analysis

Public systems planning and analysis involves the application of systems engineering, economic and political theory, and environmental law to public sector problems including environmental quality management, the planning and operation of transportation systems, water resource development, waste residuals management, public health services, and other urban and regional planning problems. It is concerned with the development of improved methods for defining and evaluating alternatives for allocating resources and enhancing the quality of information upon which public investment decisions are made. Current emphasis is placed on transportation systems; air, water, and other natural resource systems; project management; residuals-environmental quality management; and public health, medical, and public service systems.

Graduate students interested in Public Systems Planning and Analysis may major in either Environmental Systems or Transportation (at either the M.S. or Ph.D. level) or in Water Resource Systems (at the Ph.D. level only).

The College Program

Carpenter Hall

Degree Offered: Bachelor of Science

College Program Committee: Mr. W. H. Erickson, chairman; Messrs. B. Boley, R. K. Finn, B. Gebhart, H. H. Johnson, M. Nelkin, C. Pottle.

The College Program is devised to give engineering students an opportunity to pursue novel and interdisciplinary courses of study. Students whose educational needs and career objectives cannot be satisfied by one of the Field Programs the College offers may choose to enter the College Program. In it they will develop their own program of studies consistent with their own special interests. Students in the College Program over the past five years have combined their engineering studies with studies in biology, architecture, city and regional planning, ecology and conservation, and the physical and social sciences. Some have combined two engineering fields (for instance, electrical engineering and industrial engineering) while others have concentrated on one area of an established engineering field (for example, structural engineering). In planning a College Program, a student should thoughtfully and carefully consider his future educational and professional objectives, and in particular the prerequisites for any formal graduate study in which he may be interested.

Each College Program is highly individualized, and is worked out between the student and his advisers. All College Programs, however, consist of an engineering major and a minor. The minor may be one offered by the College of Engineering or by some other unit of the University. Students have pursued minor areas of specialization or course work in the College of Agriculture, the College of Architecture, Art, and Planning, the College of Arts and Sciences, the School of Industrial and Labor Relations, and the College of Human Ecology. Graduates of the College Program have continued their education in physical sciences, medicine, business, and law as well as in engineering. Some recent examples of major and minor combinations are: airphoto interpretation and conservation or geology; computer science and electrical systems or industrial engineering; electrical engineering and industrial engineering; electrical systems and biological science or computer science; engineering science and aerospace engineering, biological science, or materials science; environmental quality and ecology; environmental systems and city planning or regional planning; industrial engineering and computer science; materials science and biological science or chemistry; mechanical engineering and biological science or oceanography; and transportation and regional planning. Partially structured programs sponsored by groups of interested faculty members are listed below.

Admission

Students may apply to enter the College Program at the beginning of the second term of the sophomore year. Entry is in the junior year, after all requirements of the Division of Basic Studies have been met. Included in the application materials will be a statement of objective and a term-by-term listing of the courses the student proposes to take to meet his objective. It is expected that the student will develop this program with the help of technical consultants in the fields of his proposed major and minor, after discussing his objective with a member of the College Program Committee. The technical consultants may be professors recommended to the student by College Program Committee members, or professors whom he has encountered on his own.

Application forms may be obtained from the College Program Office, 221 Carpenter Hall. After the application has been endorsed by the professor representing the proposed major and minor areas, it is submitted to this Office and is then either approved or disapproved by the College Program Committee.

No minimum grade-point average is required for admission, but underclass performance will be a consideration.

Degree Requirements

Once admitted to the College Program, the student's progress is under the supervision of the College Program Committee. His advisers are the faculty members who endorsed his program, and any course changes must be approved by them. A change in the major or minor area must be approved by the Committee, which is responsible for all of the administrative functions normally performed by the faculty of a Field Program.

Specific requirements for the Bachelor of Science degree in a College Program are: (1) a minimum of forty-two credit hours of an approved program (which is to consist of a major area and an educationally related minor); (2) a minimum of twelve credit hours of liberal studies electives; (3) a minimum of six credit hours of free electives (which may be taken in the major or minor areas).

Majors are possible in each of the Fields of Engineering offered by the College and in the Departments of Computer Science and of Theoretical and Applied Mechanics.

Special Sponsored College Programs

College Program in Engineering Science

Faculty members of the Department of Theoretical and Applied Mechanics have formulated a program in engineering science which they are prepared to endorse. The program has the general format outlined below.

Term 5
Engineering Science
Thermodynamics
Math or Engineering Analysis*
Physics or Engineering Science
Liberal Studies Elective

Term 6
Engineering Science
Fluid Mechanics
Math or Engineering Analysis*
Physics or Engineering Science
Liberal Studies Elective

Term 7
Physics or Engineering Science
Math or Engineering Analysis*
Intermediate Dynamics
Free Elective
Liberal Studies Elective

Term 8
Physics or Engineering Science
Math or Engineering Analysis*
Continuum Mechanics
Free Elective
Liberal Studies Elective

* Substitution of a one-year course in experimental mechanics or physics for a one-year course in mathematics may be arranged.

A further discussion of this program may be found on p. 49.

College Program in Computer Science

A student interested in concentrating in the area of computer science during his upperclass years should consult with a faculty member from the Department of Computer Science who will help in formulating an appropriate College Program. A typical computer science major might consist of the following courses offered by the Department of Computer Science.

202, Computers and Programming (engineering core science)
203, Discrete Structures
222, Introduction to Numerical Analysis
385, Introduction to Automata Theory
409, Data Structures
411, Programming Languages
412, Translator Writing
413, Systems Programming and Operating Systems
(Descriptions of these courses may be found on pp. 71–72.)

There is considerable flexibility in devising a College Program in Computer Science. Other courses than the ones listed above may be taken, depending on the student's interests.

College Program in Energy Conversion

Students desiring a broadly based engineering curriculum aimed at meeting the accelerating energy needs of society may consider the College Program in Energy Conversion, which combines elements of three conventional disciplines: nuclear, thermal, and electrical engineering. Interested students should consult a member of the faculty group sponsoring the College Program in Energy Conversion: K. B. Cady and D. D. Clark, Ward Reactor Laboratory; B. J. Conta and F. K. Moore, Upson Hall; and S. Linke and C. B. Wharton, Phillips Hall.

A typical curriculum is outlined below. This sample curriculum assumes that the student has taken 3631, Introduction to Thermodynamics, and 4210, Introduction to Electrical Systems, as two of his sophomore engineering core sciences.

Term 5
1150, Advanced Engineering Analysis I
3623, Fluid Mechanics
4321, Electrical Laboratory I
8301, Nuclear Energy and the Environment
Liberal Studies Elective

Term 6
1151, Advanced Engineering Analysis II
3672, Energy Conversion
4322, Electrical Laboratory II
8303, Nuclear Science and Engineering
Liberal Studies Elective

Term 7
3625, Heat Transfer and Transport Processes
4445, Electric Energy Systems I
8312, Nuclear Reactor Theory I
Free Elective
Liberal Studies Elective

Term 8
3641, Power Systems
4446, Electric Energy Systems II
8351, Nuclear Measurements Laboratory
Free Elective
Liberal Studies Elective

By use of electives and substitutions and with attention to prerequisites, it is possible for the student to include several of the following:
4561, Introduction to Plasma Physics
4464, Elementary Plasma Physics and Gas Discharges
4481, Feedback Control Systems I
4482, Feedback Control Systems II
3663, Turbomachinery
3652, Combustion Theory
3642, Pollution Problems
3656, Advanced Thermal Engineering Laboratory
Biology 101, Biological Science
8333, Nuclear Reactor Engineering
8334, Nuclear Engineering Design Seminar
2603, Engineering Economics and Systems Analysis

College Program in Public Systems Planning and Analysis

A program in Public Systems Planning and Analysis has been formulated by the faculty of the Department of Environmental Engineering of the School of Civil and Environmental Engineering. The core courses for this program, shown below, should be supplemented by additional work in the student's major area of interest, such as transportation, urban planning, or systems analysis.

Systems analysis courses
Engineering 9320 or 9522
Engineering 9321 or 9523
One course in computer science*

Economics courses
Engineering 2611 and 2612*
One additional upper-level course in economics (e.g., Engineering 2613, Economics 301, Consumer Economics and Public Policy 480†).

Probability and statistics courses
Engineering 9160*
Engineering 9370

Applications courses
City and regional planning (e.g., City and Regional Planning 412 or 510‡)
Transportation (e.g., Engineering 2620 or 2621)
Environmental quality (e.g., Engineering 2501, 2533, 2532)
Environmental law (Engineering 2605)
Public systems analysis (Engineering 2617 and 2618)

* Indicates course which could be taken in the Division of Basic Studies.
† Offered by the College of Human Ecology.
‡ Offered by the College of Architecture, Art, and Planning.

Computer Science

(Colleges of Engineering and of Arts and Sciences)

Upson Hall

Degrees Offered: Master of Science, Doctor of Philosophy.

Mr. G. Salton, chairman; Messrs. J. R. Bunch, R. L. Constable, R. W. Conway, J. E. Dennis, Jr., D. Gries, J. Hartmanis, J. E. Hopcroft, E. Horowitz, W. L. Maxwell, J. Moré, H. L. Morgan, C. Pottle, R. E. Tarjan, R. J. Walker, J. H. Williams.

Courses of instruction are listed on pp. 71–74.

Computer science is a relatively new field of study that draws on and contributes to a number of other disciplines such as mathematics, engineering, linguistics, and psychology. Developments in this field are also useful in research, development, design, and management activities in the various functional areas of engineering and applied science.

At Cornell, computer science is concerned with fundamental knowledge in automata, computability, programming languages, and systems programming, as well as with subjects (such as numerical analysis and information processing) which underlie broad areas of computer applications. Because of the wide implications of research in the field, the Department of Computer Science is organized as an intercollege department in the College of Arts and Sciences and the College of Engineering.

Computing Facilities

The principal computing facility at Cornell is an IBM 360 Model 65, located in Langmuir Laboratory at the Cornell Research Park on the periphery of the campus and directly linked to satellite computers at three different campus locations. The College of Engineering is served through one of these satellite stations in Upson Hall as well as by a number of teletypewriter terminals in different locations. An IBM 1800 computer is also available to provide an analog-digital interface and graphical display equipment.

The Degree Programs

The Undergraduate College Program

Although the Department teaches a comprehensive set of undergraduate courses, there is no undergraduate field program in computer science in the College of Engineering. To major in computer science the student may utilize the College Program leading to the degree of Bachelor of Science (see p. 33 for a description of a typical College Program in Computer Science). Each program must be approved after formulation by the student and cannot be specified in an approved form in advance; students interested in a computer science major should consult with a computer science faculty adviser who will help in formulating the appropriate College Program.

Master of Science and Doctor of Philosophy

In the Field of Computer Science, qualified graduate students can earn Master of Science and Doctor of Philosophy degrees.

Graduate students who are interested in the theory, design, and use of automatic computing equipment as a subject in itself should consider the opportunities for advanced training in computer science. In general, they are expected to have a strong background in mathematics, science, or engineering, although students with exceptional records from other fields will also be considered for admission. Students with an interest in the application of computers to their own major fields should consider a graduate minor in computer science to supplement their major field of study. Opportunities for research and study exist in the following areas of computer science: numerical analysis, programming languages and systems, automata and computability theory, information organization and retrieval, and analysis of algorithms.

The program for the M.S. degree involves one year of graduate-level course work and the writing of a thesis. Before the degree is awarded, a candidate must pass a comprehensive examination covering his course work and his thesis.

A Ph.D. program usually involves approximately two years of graduate-level course work, the demonstration of ability to read scientific literature in one foreign language (usually chosen from French, German, and Russian), the passing of a comprehensive oral examination, the writing of a dissertation, and a final oral examination on the dissertation. The dissertation must demonstrate the ability of the candidate to conduct an original and independent investigation of high quality and to present the results of the research in a well-organized and cogent manner.

It is possible to obtain the Ph.D. degree without first receiving the M.S. degree, or to obtain the M.S. only. Further information about the Department's teaching and research activities is summarized in a brochure entitled *Computer Science at Cornell.* It may be obtained from the Field Representative, Department of Computer Science, Upson Hall.

Electrical Engineering

Phillips Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Electrical), Master of Science, Doctor of Philosophy.

Mr. H. J. Carlin, director; Mr. J. L. Rosson, assistant director; Messrs. P. D. Ankrum, J. M. Ballantyne, T. Berger, R. Bolgiano, Jr., N. M. Brice, N. H. Bryant, R. R. Capranica, G. C. Dalman, L. F. Eastman, W. H. Erickson, D. T. Farley, T. L. Fine, J. Frey, T. Gold, F. Jelinek, M. Kim,

W. H. Ku, C. A. Lee, R. L. Liboff, S. Linke, R. A. McFarlane, H. S. McGaughan, P. R. McIsaac, J. A. Nation, B. Nichols, R. E. Osborn, E. Ott, C. Pottle, H. G. Smith, R. N. Sudan, G. Szentirmai, C. L. Tang, J. S. Thorp, H. C. Torng, N. M. Vrana, C. B. Wharton, G. J. Wolga, S. W. Zimmerman.

Courses of instruction are listed on pp. 74–82.

The curriculum leading to the degree of Bachelor of Science in the Field Program of the School of Electrical Engineering is intended to create in the student an understanding of the meaning and the application of those physical laws that are basic to electrical engineering and, at the same time, to provide the opportunity for as much study in the fields of humanities and social studies as is consistent with the objectives of modern education in the field of engineering. The successful completion of this degree program qualifies the student to pursue one of three possible routes to advanced studies.

1. Graduate studies in the Field of Electrical Engineering leading to the degree of Master of Engineering (Electrical). This degree is awarded for successful completion of a structured curricular program and is intended for a student who expects to practice electrical engineering as a profession but does not plan to engage in research as a career. (See p. 37 for a general description of requirements.)

2. Graduate studies leading to the degree of Master of Science or Doctor of Philosophy. Either of these degrees involves residence on the campus and submission of a thesis and is intended for students who plan to engage in research as a career. The requirements for this degree are described in the *Announcement of the Graduate School*.

3. Advanced studies in nonengineering fields such as law and business administration.

The education of the modern electrical engineer, as represented by the successful completion of the requirements for the degree of M.Eng. (Electrical), provides a sound foundation for him to practice electrical engineering successfully in a rapidly expanding field including such areas as random, time variable, linear, and nonlinear systems and circuits; quantum electronics; plasma physics; magnetohydrodynamic power generation; space communication and control systems; design of switching circuits; digital processing of signals; computer-aided design; microwave propagation; radio physics; digital circuits, integrated circuits, and solid state microwave devices; and bioelectronics. In establishing this curriculum, the faculty of the School of Electrical Engineering has recognized the enormous scope of electrical engineering today and has concluded that adequate preparation in electrical engineering requires education in three main areas: *Electrophysics, Systems,* and *Laboratory*. The curriculum contains an integrated series of required courses in each of these interrelated areas.

Electrophysics is chiefly concerned with present understanding of the physical laws that govern the design or application of electrical devices. Modern devices from machines to lasers are based on the laws governing electric and magnetic fields, interaction of fields and particles, fluid flow, kinetic theory, thermodynamics, quantum mechanics, properties of materials in the solid state, plasmas, and bioelectronics. In the curriculum, these subjects are treated in significant depth and breadth. All undergraduate students enrolled in the Electrical Engineering Field Program are required to complete 4311, 4312, and 4411 as a sequence of electrophysics courses.

The *Systems* sequence deals with the laws that govern the interaction of devices whose individual behavior is specified, the response of these systems to various inputs, and the design of systems to perform a variety of functions. These systems may be solely electrical or involve transducers; they may contain both linear and nonlinear elements; they may be passive, active, or random. The program is designed to develop competence in the general methods of analysis required for such systems, understanding of the physical significance of the solutions, and knowledge of some aspects of the design of systems for power distribution, computation, control, electronic circuits, communications, pattern classification, instrumentation, and biological systems. All undergraduate students enrolled in the Electrical Engineering Field Program are required to complete 4301, 4302, and 4401 as a sequence of courses in the systems area of study.

The *Laboratory* sequence emphasizes the concept that new developments in engineering practice come from a blend of theory and experimentation. Laboratory work in systems and electrophysics includes experiments in electronic circuits, instrumentation, machinery, electromagnetics, microwaves, solid state devices, computer applications and simulation, deterministic and random signal channels, etc. Each of the third-year laboratory courses involves two laboratory periods each week. Sufficient time and flexibility are provided to allow for individual exploration, and the goal is to enable the student to devise his own experiments. All undergraduate students enrolled in the Electrical Engineering Field Program are required to complete 4321, 4322, and six additional hours of electrical engineering electives with laboratory.

Laboratory and Research Facilities

A wide variety of excellent facilities are available for both undergraduate and graduate students enrolled in the Field of Electrical Engineering. Most of the undergraduate and graduate instruction is given in Phillips Hall, a modern building with more than 100,000 square feet of floor space. In addition to the classrooms, offices for faculty and graduate students, conference rooms, and machine and electronics shops, there are two undergraduate laboratory areas—each covering approximately 6,000 square feet. Each laboratory is served by a stockroom containing the most modern electrical and electronic equipment and related instruments needed to implement the laboratory sequence of courses. A number of electrical engineering laboratories are devoted solely to graduate studies and research programs. Among these are laboratories for research in systems and networks, including control systems, analog computers, and switching circuits; microwave electronics, bioelectronics, physical and solid state electronics, quantum electronics including high power lasers, plasma and gas discharge phenomena, and high-energy pulse power. The internationally known Arecibo Observatory in Puerto Rico is used for research studies of the upper atmosphere and for radio-astronomy and radar-astronomy research. Facilities at the Observatory include two radar transmitters, each having a peak-power output of 2,500,000 watts and operating in conjunction with a 1,000-foot-diameter antenna.

The Degree Programs

Bachelor of Science

Entry into the Field of Electrical Engineering comes after completion of the first two undergraduate years in the Division of Basic Studies. The upperclass program of study is outlined below.

Term 5	
4301, Analysis of Electrical Systems I	4
4311, Electromagnetic Fields and Waves	4
4321, Electrical Laboratory I	4
Liberal Studies Elective	3
Technical or Free Elective*	3
Term 6	
4302, Analysis of Electrical Systems II	4
4312, Electromagnetic Fields and Waves	4
4322, Electrical Laboratory II	4
Liberal Studies Elective	3
Technical or Free Elective*	3
Term 7	
4401, Random Signals in Systems	4
4411, Quantum Theory and Applications	4
E. E. Elective with laboratory	3 or 4
Liberal Studies Elective	3
Technical or Free Elective*	3
Term 8	
E. E. Elective with laboratory	3 or 4
E. E. Elective†	3 or 4
E. E. Elective†	3 or 4
Liberal Studies Elective	3
Technical or Free Elective*	3

* During enrollment in the Electrical Engineering Field Program, a student must satisfactorily complete two technical and two free electives. The order in which these elective requirements are fulfilled is the student's choice.

† Students having special career goals may propose appropriate technical or professional electives to substitute for the Electrical Engineering electives. The approval of the adviser is required for such substitutions.

A wide selection of elective courses in the Field of Electrical Engineering is available to fourth-year students. For such students, approval of the instructor is required for admission to courses with numbers in the 4500's or above. The Field electives are:

Theory of Systems and Networks

4450, Bioelectric Systems
4453, Introduction to Biomechanics, Bioengineering, Bionics, and Robots
4475, Active and Digital Network Design
4478, Computer Methods in Electrical Engineering
4503, Theory of Linear Systems
4504, Theory of Nonlinear Systems
4507–08, Random Processes in Electrical Systems
4571, Network Analysis
4572, Network Synthesis
4575, Computer Aided Network Design

Electronics

4412, Solid State Physics and Applications
4430, Introduction to Lasers and Optical Electronics
4431–32, Electronic Circuit Design
4433–34, Semiconductor Electronics I and II
4436, Electronic Processing of Audio Signals
4437–38, Solid State Microwave Devices and Subsystems
4531–32, Quantum Electronics I and II
4534, Nonlinear and Quantum Optics
4535–36, Solid State Devices I and II
4537, Integrated Circuit Techniques
4631–32, The Physics of Solid State Devices

Power Systems and Machinery

4441–42, Contemporary Electrical Machinery I and II
4443, Power System Equipment
4444, High Voltage Phenomena
4445–46, Electric Energy Systems I and II

Communications, Information, and Decision Theory

4473, Coding Algorithms
4474, Fundamental Information Theory
4476, Statistical Aspects of Communication
4672, Foundations of Inference and Decision Making
4673, Principles of Analog and Digital Communication
4674, Advanced Information Theory
4676, Decision and Estimation Theory for Signal Processing

Computing Systems and Control

4481–82, Feedback Control Systems
4483, Analog Computation
4484, Analog-Hybrid Computation
4487, Switching Circuits and Logic Design
4488, Structures of Computing Systems
4505, Estimation and Control in Discrete Linear Systems
4506, Optimal Control and Estimation for Continuous Systems
4580, Machine Organization
4681, Random Processes in Control Systems

Radio and Plasma Physics Electromagnetic Theory
4461, Wave Phenomena in the Atmosphere
4462, Radio Engineering
4464, Elementary Plasma Physics and Gas Discharges
4511, Electrodynamics
4514, Microwave Theory
4551–52, Upper Atmosphere Physics I and II
4561, Introduction to Plasma Physics
4564, Advanced Plasma Physics
4565–66, Radiowave Propagation I and II
4567, Antennas and Radiation
4661, Kinetic Equations

Courses of Interest to Other Curricula
4110, Computer Appreciation
4210, Introduction to Electrical Systems
4435, Electronics and Music
4921–22, Electrical Engineering Laboratory
4940, Introductory Electrical Engineering

The scholastic requirement for electrical engineering students is a minimum grade-point average of 1.8 (see p. 12) in third- and fourth-year courses. A student failing to make satisfactory progress toward his degree, as evidenced by a low average, by course failures, or by low grades in major courses, may be allowed a trial term or may be suspended from the School.

Master of Engineering (Electrical)

Admission to the Master of Engineering (Electrical) degree program is open to persons who have been granted Bachelor's degrees or the equivalent and who have adequate preparation for profitable study of the advanced courses offered for these students in the School of Electrical Engineering. The purpose of this degree program is to offer depth of study in both comprehensive and specialized electrical engineering subjects and to offer study which can extend the abilities of the electrical engineer to other fields.

The requirements for the M.Eng. (Electrical) degree are as follows.

1. A minimum of thirty credit hours of advanced technical course work in the Field of Electrical Engineering or in related subjects.

2. A minimum of four courses in advanced electrical engineering consisting of two approved pairs chosen from a designated list on file with the M.Eng. (Electrical) adviser.

3. A minimum of three credit hours of engineering design experience involving individual effort and a formal report. Design projects are often sponsored by industry and governmental agencies. Recent projects have included the design of an electric automobile, a radio deer-tracking system for conservation purposes, and a remotely controlled vehicle for exploring planetary surfaces.

4. A minimum grade point average of 2.5 (see p. 12) and a minimum final grade of 2.0 for all courses that count toward the degree requirements.

There are no residence requirements, although all course work must, in general, be completed under Cornell University staff instruction. The degree requirements must normally be completed within a period of four calendar years.

Graduates of Cornell University with a Bachelor of Electrical Engineering degree may be granted up to fifteen hours of credit for advanced courses taken during the fifth undergraduate year, provided they enter the M.Eng. (Electrical) program not later than the fall term following the sixth anniversary of their receipt of the B.E.E. degree. For those students who are granted fifteen credit hours of advanced standing, the requirement is six credit hours in the School of Electrical Engineering rather than two-course sequences, and the design requirement may be waived.

Master of Science and Doctor of Philosophy

The requirements for the degrees of Master of Science and Doctor of Philosophy are described in the *Announcement of the Graduate School.* These are research degrees that involve residence on the campus and submission of a thesis.

In the School of Electrical Engineering, research work leading to these degrees may be undertaken in the area of *electrophysics* including radio propagation, radio and radar astronomy, electromagnetics, plasma physics, magnetohydrodynamics, physical and microwave electronics, microwave solid state devices, electronic processing of music, materials science and solid state physics in electrical engineering, quantum electronics and laser optics, biomedical electronics, electric power conversion, electrical breakdown phenomena, etc., or in the area of *systems* including information theory, network theory, communications systems, control systems, switching circuits, computers and computer-aided design, cognitive systems, etc. A number of fellowships, research assistantships, and teaching assistantships are available to candidates for the M.S. and Ph.D. degrees who are doing their thesis research in the School of Electrical Engineering.

A brochure describing research activities, assistantship applications, and further information may be obtained from the Graduate Field Representative, School of Electrical Engineering, Phillips Hall.

Environmental Engineering

See p. 29.

Geological Sciences

(Colleges of Engineering and of Arts and Sciences)

Kimball Hall

Degrees Offered: Bachelor of Science, Master of Science, Doctor of Philosophy.

Mr. J. E. Oliver, chairman; Messrs. A. L. Bloom, B. Bonnichsen, B. Isacks, G. A. Kiersch, S. S. Philbrick, O. Sardi, J. W. Wells.

Courses of instruction are listed on pp. 82–85.

Study in geological sciences is offered for students who are preparing to be professional geologists, for those who wish a broad background in the geological sciences as preparation for careers in such related fields as environmental or conservation work, or for those who wish to combine geological training with other sciences such as agronomy, astonomy and space science, biological sciences, chemistry, economics, mathematics, physics, or various fields of engineering. The organization of the Department of Geological Sciences as an intercollege department in the College of Arts and Sciences and the College of Engineering facilitates the structuring of individualized programs of study.

At the graduate level, interdisciplinary programs lead to the Master of Science and Doctor of Philosophy degrees in Geological Sciences. Also, this Field may be studied as a minor subject in the Master of Engineering degree program (see p. 10).

Laboratory and Research Facilities

Well-equipped geological sciences laboratories, augmented by special and advanced equipment available through other units of the University, provide excellent opportunities for research. Also, the Paleontological Research Institution, a private research organization, is located near the campus and its facilities are available to the specialized investigator.

The Ithaca region is particularly suited for research in stratigraphy, paleontology, geomorphology, and glacial geology, and the nearby Adirondack area is a classic one for studies in metamorphic and igneous petrology.

Field sites in western as well as northeastern states and in Labrador are available for research projects in structural geology, geomechanics, engineering geology, hydrogeology, mineral deposits, physical geography, and areal geology. The Department has a cooperating agreement with the Museum of Northern Arizona at Flagstaff, for accommodating research projects and investigators in a varied field setting. The Committee for Labrador Studies has been sponsoring research in Labrador for forty years, and projects are in progress on field mapping, glacial geology, and petrography.

The Department owns outstanding reference collections of minerals, ores, fossils, and recent mollusks.

The Degree Programs

Bachelor of Science

In the College of Engineering, a major in geological sciences may be taken in the upperclass years through the College Program (see p. 31). Each Program is formulated on an individual basis by the student in consultation with his faculty adviser, and must be approved by the College Program Committee.

Master of Science and Doctor of Philosophy

The program of graduate study in the Field of Geological Sciences is designed to give broad training in both the field and the laboratory.

A major subject may be selected from the following areas: areal and environmental geology; engineering geology; geohydrology and hydrogeology; geomorphology; geochemistry, mineralogy-petrology; geophysics; geobiology, paleontology, and stratigraphy; mineral deposits, mining geology; physical geography; and structural geology and geomechanics. A strengthening of the Field's curriculum and graduate research in the earth sciences is being planned; areas of specialization will include seismology, tectonophysics, geomagnetics, marine geology, and glaciology.

Minor subjects for students with a major in geological sciences are selected from other fields such as agronomy, botany, engineering, chemistry, mathematics, physics, materials science, water resources, zoology, the biological sciences, or certain nonscientific fields. Ph.D. degree candidates select two minor subjects, and M.S. degree candidates choose one.

Cooperative graduate programs in many interdisciplinary areas are available. Oceanography and marine ecology are offered in cooperation with the Division of Biological Sciences and the Department of Conservation; research projects are in progress in the Long Island coastal areas, and cooperative research is undertaken at the Woods Hole Oceanographic Institute, the Cornell Marine Laboratory at the Isles of Shoals in the Gulf of Maine, and the Mote Marine Laboratory at Sarasota, Florida. Study in water resources is available through the University's Water Resources and Marine Sciences Center; courses of study include a professional scientific hydrology program. Cooperative programs of study in applied branches of geological science combine a major in mining geology-mineral deposits, petroleum geology, hydrology and geohydrology, or engineering geology, with minors in such subjects as soil science, hydraulics, water resources engineering, soil mechanics, materials engineering, mathematics, chemistry, physics, economics, and regional planning.

Detailed information about the M.S. and Ph.D. programs is given in the *Announcement of the Graduate School.* A brochure describing graduate study in Geological Sciences may be obtained by writing to the Field Representative, Kimball Hall.

Industrial Engineering and Operations Research

Upson Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Industrial). The programs in this

Field are administered by the School of Industrial Engineering and Operations Research. The Graduate Field of Operations Research offers the Master of Science and Doctor of Philosophy degrees; see p. 47.

Mr. B. W. Saunders, director; Messrs. R. N. Allen, R. E. Bechhofer, L. J. Billera, M. Brown, R. W. Conway, M. J. Eisner, H. Emmons, D. R. Fulkerson, H. P. Goode, W. F. Lucas, W. L. Maxwell, H. Morgan, G. L. Nemhauser, N. U. Prabhu, S. Saltzman, M. W. Sampson, A. Schultz, Jr., S. Stidham, Jr., L. I. Weiss. Visiting staff: Mr. C. R. Glassey.

Courses of instruction are listed on pp. 85–89.

The function of the industrial engineer is, broadly defined, to bring together men, machines, materials, and information to facilitate an effective operation. Essentially, the industrial engineer is engaged in the "design" of a "system," and his function is primarily that of management.

The scope and methods of industrial engineering have expanded greatly within the last decade in response to new and increased needs of public and private organizations and the availability of new tools and skills. Twenty years ago nearly all industrial engineering was practiced in the manufacturing phase of the mechanical goods industries. The modern expansion of the field finds many new titles used instead of the former identification as simply industrial engineering. Today, Cornell's program in industrial engineering encompasses areas such as operations research; manufacturing, production, and automation engineering; and even human engineering. Students are prepared to be systems engineers, management or administrative engineers, and operations engineers. Graduates are working in the fields of transportation, distribution, military logistics, weapons systems analysis, finance, public health, and the service industries, as well as in manufacturing.

The curriculum in industrial engineering at Cornell offers the student a wide range of opportunity beyond the traditional mechanical manufacturing technology. A flexible, elective program emphasizing mathematics leads to the Bachelor of Science degree in four years and the Master of Engineering (Industrial) degree after a coordinated fifth year of study.

Laboratories and Research Facilities

The School of Industrial Engineering and Operations Research is housed in Upson Hall, where available facilities include a remote terminal of the University's IBM 360 Model 65 computer (see p. 34). The School is one of the principal users of the University's Computing Center, which constitutes a basic laboratory for students of industrial engineering and operations research. Computer-based work is especially important in upperclass courses and in graduate research. Many research problems and projects in engineering design are supplied by industrial plants located in the area, by University operations, and by certain community activities. Upson Hall facilities also include a methods laboratory and computing rooms equipped with desk calculators.

The Degree Programs

Bachelor of Science

The first two years of undergraduate study are administered by the Division of Basic Studies (see p. 19). Students may enter the Field of Industrial Engineering and Operations Research in their junior year.

During their sophomore year, students who plan to major in industrial engineering and operations research should elect, as one of their four engineering core courses, Introductory Engineering Probability (9160). Computers and Programming (202) is also a good core science choice, as it is required for the upperclass program; if this is taken in the Division of Basic Studies, an additional technical elective may be selected in term 5.

As a result of continual updating of curricula, the pattern of courses to be followed will vary somewhat for the class of 1972 and the classes of 1973 and beyond. The class of 1972 will complete the following sequences.

Term 7	*Hours*
9310, Industrial Systems Analysis	4
9320, Deterministic Models in IE/OR	4
Technical Elective	3
Free Elective	3
Liberal Studies Elective	3
Term 8	
9311, Industrial Systems Design	4
9361 (formerly 9321), Probabilistic Models in IE/OR	4
Technical Elective	3
Free Elective	3
Liberal Studies Elective	3

A more flexible curriculum, providing both breadth and depth of study in certain aspects of the field, is designed for the class of 1973 and those which follow. This curriculum includes a required core of seven courses and allows for two two-course sequences chosen from four areas: *Industrial Systems, Information Systems, Applied Probability and Statistics, and Optimization.* The student also selects four liberal studies electives, two technical electives, and two free electives, as required by the College of Engineering. He completes an upperclass program of twenty courses by selection of one additional technical or behavioral science elective (or two such electives if he took Computer Science 202 in his sophomore year). The elective courses can be chosen so as to emphasize some special area of technology (e.g., manufacturing processes, environmental processes, urban and regional planning, transportation system technologies, computer science and/or computer technologies) or, for research-minded students, could consist of basic courses in mathematics.

In summary, the upperclass program is as follows.

Required Common Core
(to be taken not later than Term 6)

	Hours
Computer Science 202, Computers and Programming	3
9320, Deterministic Models in IE/OR (prerequisite: Mathematics 293)	4
9350, Cost Accounting, Analysis and Control	4
9361, Probabilistic Models in IE/OR (prerequisite: 9160)	4
9370, Introduction to Statistical Theory with Engineering Applications (prerequisite: 9160)	4
9383, Applications of Computer Science in IE/OR (prerequisite: C.S. 202)	4
A behavioral science (selected from an approved list)	3

Options
In terms 7 and 8 a selection is made of any two of the following four sequences, each of which consists of two courses.

	Hours
Industrial Systems:	
9310, Industrial Systems Analysis (prerequisite: 9370 and 9350)	4
9311, Industrial Systems Design (prerequisite: 9310 and 9320)	4
Information Systems:	
9582, Data Processing Systems (prerequisite: C. S. 202)	4
Computer Science 203, Discrete Structures (prerequisite: C.S. 202)	3
Applied Probability and Statistics:	
9560, Applied Stochastic Processes (prerequisite: 9361)	4
9570, Intermediate Statistics (prerequisite: 9370)	4
Optimization Methods:	
9530, Mathematical Programming (prerequisite: 9320)	3
9135, Introduction to Game Theory	3

Because of the degree of flexibility afforded by the Field Program in Industrial Engineering and Operations Research, it is recommended that the student initiate early and frequent contact with his adviser.

Scholastic requirements for the Field are a passing grade in every course, maintenance of a grade-point average of at least 2.0 (see p. 12), and, in general, satisfactory progress toward completion of the degree.

Master of Engineering (Industrial)

This one-year degree program is integrated with the Cornell undergraduate degree program in industrial engineering and operations research. Those who apply during their senior year will generally be admitted to the program if their past performance indicates their ability to do Master's degree work. The course work centers on additional study of analytical techniques with particular emphasis on their engineering applications, especially in the design of new or improved man-machine systems, information systems, and control systems.

Applications will also be considered from non-Cornellians who have (or will have earned) a Bachelor's degree in a field of engineering from an institution of recognized standing, have adequate preparation for graduate study in industrial engineering, and show promise of doing well in advanced study as judged by previous scholastic records or other achievements.

This professional degree is design-oriented rather than research-oriented and requires completion of an engineering design project. In addition to this project, which carries eight hours of course credit, the curriculum includes a minimum of twenty-two hours of required or relevant elective course work. The program is as follows:

Required Courses	*Hours*
9521, Production Planning and Control (prerequisite: 9320 and 9361)	4
9526, Mathematical Models–Development and Application (prerequisite: 9320 and 9361)	4
9580, Digital Systems Simulation (prerequisite: 9370 and C.S. 202)	4
9598, Project work	4
9599, Project work	4
9593–94, Seminar	2
Elective Courses in Engineering	9

Materials Science and Engineering

Bard Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Materials), Master of Science, Doctor of Philosophy.

Mr. H. H. Johnson, director; Messrs. D. G. Ast, R. W. Balluffi, B. W. Batterman, J. M. Blakely, M. S. Burton, P. S. Ho, E. J. Kramer, C. Y. Li, A. L. Ruoff, S. L. Sass, E. Scala, D. N. Seidman. Visiting staff: Mr. B. S. Borie.

Courses of instruction are listed on pp. 89–91.

In all areas of modern technology, advances in system efficiency and economy are often limited by the properties of available materials. Significant technological breakthroughs in diverse fields such as structures, power, communications, propulsion, chemical processing, or transportation frequently are a direct result of improvements in materials—either the development of new materials or the evolutionary improvement of existing ones. Materials scientists and materials engineers are therefore in demand in virtually all segments of modern industrial-technological society.

As the field exists today, it is perhaps best described as a fusion of the traditional interests of the metallurgist with the basic understanding and wide scientific interest of the solid state physicist and chemist. The distinguishing "theme" of this field is the relation between the structure of materials and their properties. The structure of solids encompasses such specific aspects as crystalline structure and imperfections, molecular arrangement, phase composition and morphology, and grain size. These and other characteristics from the atomic to the macroscopic scale control the behavior of a material. Materials science is concerned with the understanding of these characteristics and with methods of influencing them, and materials engineering deals with applications, particularly with the selection, processing, characterization, and testing of materials.

Laboratory and Research Facilities

The Department of Materials Science and Engineering is centered in Bard Hall and occupies parts of Thurston and Kimball Halls, a total area of 50,000 square feet. Bard Hall, the newest of the Cornell engineering buildings, was completed in 1963 and is extensively equipped for both undergraduate and graduate instruction and research. Facilities for characterizing and studying the structure of solids by physical measurement, microscopy, metallography, and x-ray diffraction are available. Included is equipment for processing materials by casting, welding, heat treatment, compacting and sintering, deformation, and many of the newer processing procedures such as crystal growth and deposition from the vapor phase. Laboratories for preparing and studying nonmetallic materials, especially ceramics, are also housed in Bard Hall.

This Department participates with other departments of the University in the interdisciplinary Materials Science Center. The Center supports central facilities in Bard, Thurston, and Clark Halls for service and research in metallography, x-ray diffraction, electron microscopy, mechanical testing, and effects of high temperature and high pressure on materials. The Materials Science Center also supports service facilities for producing, characterizing, and testing various metallic and nonmetallic materials.

The Degree Programs

Bachelor of Science

The materials science and engineering curriculum includes mathematics, physics, chemistry, and engineering sciences that are fundamental to effective work in materials science and materials engineering. The basic work on materials is contained in the required courses offered by the Department. These include discussions of crystallographic and other structural aspects, mechanical behavior, phase transformations and kinetics, and electrical and magnetic properties of materials. Laboratory courses supplement and amplify the content of lectures.

All qualified students are encouraged to take at least one year of graduate study to extend their engineering course work or their experience in laboratory investigation and research.

Course programs for terms 1–4, administered by the Division of Basic Studies, are described on p. 20. An outline of the program for the junior and senior years in the Field of Materials Science and Engineering is as follows.

	Hours
Term 5	
6031, Structure of Materials I	3
6035, Thermodynamics	3
Technical Elective	3
Technical Elective	3
Liberal Studies Elective	3–4
Term 6	
6032, Structure of Materials II	3
6034, Mechanical Properties of Materials	3
6036, Thermodynamics of Condensed Systems	3
Technical Elective	3
Liberal Studies Elective	3–4
Term 7	
6041, Kinetics	3
6043, Senior Materials Laboratory I*	3
Technical Elective	3
Free Elective	3
Liberal Studies Elective	3–4
Term 8	
6042, Electrical and Magnetic Properties	3
6044, Senior Materials Laboratory II*	3
Technical Elective	3
Free Elective	3
Liberal Studies Elective	3–4

* Physics 360 may replace one term of Senior Laboratory or a one-term project may replace one term of Senior Laboratory.

This upperclass Field Program offers students a very substantial choice of elective subjects—five technical and two free electives in addition to the liberal studies electives—during the upperclass years. Students are therefore able to supplement the required science-oriented courses with materials engineering and processing courses offered by the Department, or with electives from a very wide variety of scientific and engineering disciplines. Faculty advisers of the Department will assist each student in planning a suitable program and selecting appropriate elective courses.

The following are given as examples of elective courses. Many others are available.

Chemistry 357–358	Introduction to Organic Chemistry
Chemistry 410	Inorganic Chemistry
Chemistry 481	Advanced Physical Chemistry
Physics 360	Introductory Electronics
Physics 443	Atomic Physics and Introduction to Quantum Mechanics
Physics 454	Introductory Solid State Physics
Engineering 1150–51	Advanced Engineering Analysis
Engineering 1263	Applied Elasticity

Engineering 1267	Inelastic Behavior of Solids and Structures
Engineering 1268	Theory of Plasticity
Engineering 3331	Kinematics and Components of Machines
Engineering 3372	Experimental Methods in Machine Design
Engineering 5742	Polymeric Materials
Engineering 6039	Materials Engineering
Engineering 6045–46	Materials Processing
Engineering 6625	Composite Materials
Engineering 6764	Fracture of Materials
Engineering 6765	Amorphous and Semicrystalline Materials

The College Program. For students wishing to combine the study of materials with some other discipline, course sequences are available to provide a major or minor program in materials science and engineering. These will be selected by the student and his adviser. (See pp. 31–32 for an outline of the College Program.)

Master of Engineering (Materials)

A student who has completed a four-year undergraduate program in engineering or the physical sciences is eligible for consideration for admission to this program. The student will carry out an independent project that provides experience in defining objectives, planning and carrying through systematic work, and reporting conclusions. In addition, he will have the opportunity to develop further his knowledge and skill in specialized areas of materials science. The program includes the following:

1. A project qualifying for at least twelve hours of credit 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 credit hours of courses in mathematics or applied mathematics. This requirement may be satisfied by courses 1150 and 1151; 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 credit hours to thirty.

Master of Science and Doctor of Philosophy

Unique opportunities are open to the student undertaking graduate study in materials at Cornell. Instruction is given in a broad spectrum of topics, ranging from the fundamental aspects of materials behavior to problems associated with materials applications. Studies of metallic and nonmetallic materials, as well as some aspects of the liquid state, are incorporated into a common framework of instruction.

The Master of Science and Doctor of Philosophy programs are primarily science-oriented programs of study directed toward a career in research, development, advanced engineering, or teaching. A candidate for either degree may choose as his major subject area either *materials science* or *materials and metallurgical engineering*. Requirements for these degrees are described in the *Announcement of the Graduate School*.

A student who enters with an undergraduate degree may register for either the M.S. or Ph.D. degree. However, it is possible for a student in the M.S. program to transfer to the Ph.D. program. Toward the end of his first year, the student's progress is reviewed by his Special Committee, and if that group takes favorable action then or at a later date, the student is accepted as a Ph.D. candidate.

The courses offered by the Field assume a sound undergraduate education in such areas as mathematics, physical metallurgy, atomic and solid state physics, and thermodynamics. Graduate students enrolled with deficiencies in any of these areas will be permitted to take intermediate-level courses, with the understanding that more time may be needed to complete the degree program.

To form an adequate foundation for more specialized courses and for thesis research, the faculty has developed a core program of courses in materials science. These cover modern theories of structure and of materials behavior at an advanced level.

A significant part of the Cornell graduate educational experience is the opportunity to participate in formal and informal seminars and research conferences at which current Cornell research programs are described and guest speakers present the latest developments in other laboratories.

A brochure entitled *Research and Study in Materials Science* may be obtained from the Field Representative, Department of Materials Science and Engineering, Bard Hall.

Mechanical Engineering

Upson Hall

Degrees Offered: Bachelor of Science, Master of Engineering (Mechanical), Master of Science, Doctor of Philosophy.

Mr. D. G. Shepherd, director, Messrs. D. L. Bartel, J. F. Booker, A. H. Burr, B. J. Conta, T. A. Cool, D. Dropkin, H. N. Fairchild, B. Gebhart, F. C. Gouldin, A. I. Krauter, S. Leibovich, H. N. McManus, Jr., F. K. Moore, S. Oldberg, R. M. Phelan, K. E. Torrance, K. K. Wang, R. L. Wehe.

Courses of instruction are listed on pp. 92–97.

Mechanical engineering is the broadest of the several established fields of engineering, and the curriculum is designed to provide breadth of training. Mechanical engineers are involved in two major streams of technology: one, the transformation and utilization of energy, and the other, the design and production of goods, machines, equipment, and systems. In accordance with this broad classification there are two subject departments in mechanical engineering at Cornell: *Thermal Engineering* and *Mechanical Systems and Design* (see p. 43). Studies from these areas and others make up the Field Program.

The Field Program in Mechanical Engineering, leading to the Bachelor of Science degree after four years of study, is designed to provide the student with understanding in some depth of the engineering sciences basic to the Field and with an introduction to the professional and technical areas with which mechanical engineering is particularly concerned.

The Field Program has been arranged to provide a great deal of flexibility. Supplementary to the upperclass elective courses of the core curriculum (four liberal studies, two technical, and two free electives), two additional Field electives are offered. Furthermore, certain requirements of the Field Program can be satisfied by courses which also satisfy the underclass core curriculum. Thus a minimum of four and maximum of nine electives in technical areas are available in the third and fourth years of study.

Such flexibility requires careful planning by the student to ensure that he follows a meaningful program guided by his particular interests. To this end, some suggested programs in different areas of concentration have been set up from which students may choose courses after consulting with a faculty adviser. Such programs include courses in other divisions of the College to cover wide areas of interest. While it is not necessary to choose an area of concentration and none of the courses in these areas is mandatory, such prepared programs may be helpful to the student in choosing his program of study.

Although there is no requirement of industrial experience for any of the mechanical engineering programs at the present time, all students are urged to obtain summer employment that will broaden their knowledge of engineering. This is regarded as particularly desirable for those planning to enter the professional program for the M.Eng. (Mechanical) degree. Full use should be made of the employment opportunities available through the University and College placement services. The Engineering Cooperative Program described elsewhere in this *Announcement* should be of particular interest to mechanical engineering students. It provides for three work periods in industrial organizations yet does not delay the normal graduation date. It has particular relevance for those students interested in following through the five-year Master of Engineering degree program.

The breadth of training in mechanical engineering leads to several possibilities for advanced study following the B.S. degree. Possible programs of advanced study at Cornell include:

1. *Graduate study leading to the degree of Master of Engineering (Mechanical).* This is a curricular type of professional program intended for those students who wish to practice mechanical engineering. Although the course of study is available for all qualified students who hold a baccalaureate degree in engineering, the program is specially adapted as a graduate year of study integrated with the previous work in the Sibley School of Mechanical Engineering. It is the program commonly taken by qualified students not planning to pursue research or teaching as a career or not changing their field for advanced work. Details of this program are given on the following pages.

2. *Graduate study leading to the degrees of Master of Science or Doctor of Philosophy, with majors in either mechanical systems and design or thermal engineering.* Students planning to engage in research or teaching as a career would normally enroll in such a program. Information is given in the *Announcement of the Graduate School.*

3. *Graduate study in related fields,* such as aerospace engineering, industrial engineering, or nuclear engineering, or in different fields such as business administration, law, or medicine.

Mechanical Systems and Design

Mr. H. N. McManus, Jr., chairman; Messrs. D. L. Bartel, J. F. Booker, A. H. Burr, A. I. Krauter, S. Oldberg, R. M. Phelan, K. K. Wang, R. L. Wehe.

The Department of Mechanical Systems and Design is concerned with those aspects of mechanical engineering involving the design and/or analysis and manufacture of devices, machines, and systems. The offerings of the Department allow a student to elect courses that will equip him for a wide variety of engineering tasks; particular areas of concentration are vehicle engineering and manufacturing and design.

Vehicle engineering is concerned with the transportation needs of modern society. It includes the consideration of wheeled, tracked, and air-cushioned vehicles, and other unconventional transporters. Dynamic and safety aspects as well as structural features are considered. The course offerings are supplemented with independent projects.

Manufacturing and design is concerned with the economical design and production of material goods needed by society. Emphasis is placed on the interrelation of design and manufacture. Attention is paid to the newer production techniques (e.g., electromechanical machining, electrodischarge machining, explosive forming numerical control, and automated production) as well as the traditional methods. Independent work in specialized areas is also offered.

Thermal Engineering

Mr. F. K. Moore, chairman; Messrs. B. J. Conta, T. A. Cool, D. Dropkin, H. N. Fairchild, B. Gebhart, F. C. Gouldin, S. Leibovich, D. G. Shepherd, K. E. Torrance.

Thermal engineering is concerned with the transformation, transfer, and utilization of energy.

These concerns may be summarized as:

A. *Power and propulsion:* Conversion of energy for man's various power requirements, for electric power and transportation (terrestrial and aerospace). Students are offered relevant elective courses treating power and aerospace propulsion systems, energy conversion, combustion and transport processes, and fluid mechanics.

B. *Environmental control:* The study of environmental modification, with emphasis on sources of pollutants, their distribution through the earth's waters and atmosphere, and technical alternatives that minimize or eliminate the impact of technologically originated pollution. The creation of artificial environments is considered. Relevant electives treat pollution problems, refrigeration and air conditioning, combustion engines, and the more fundamental topics already mentioned.

Theoretical and experimental research interests include high-temperature and nonequilibrium fluid dynamics; plasma processes; flow lasers; rotating fluids with application to the confinement of high-temperature gases and to natural processes in the atmosphere and oceans; problems of heat rejection to the environment—thermal pollution; combustion processes, air pollution, and fire research; convection, conduction, and radiative heat transfer.

The Degree Programs

Bachelor of Science

The undergraduate program in mechanical engineering leads to a Bachelor of Science degree upon the successful completion of a four-year curriculum. The minimum number of credit hours required is 126.

The first two years of this program are given in the Division of Basic Studies and are substantially common to all undergraduate engineering students (see p. 19). In the sophomore year, four engineering core sciences are elected. Students desiring to pursue a program in mechanical engineering must take the course Mechanics of Solids (1021).

In the junior and senior years, a total of twenty courses is required, eight for completion of the College core curriculum and twelve for the Field Program. The eight core courses are specified as four liberal studies electives, two technical electives, and two free electives (one or both of these may be in advanced ROTC course work).

The twelve courses comprising the Field Program in Mechanical Engineering consist of nine required courses, one elective in the area of mathematics (chosen from a list of approved courses), and two Field electives (upperclass courses in the 3000 series, offered by the Sibley School of Mechanical Engineering). Of the nine required courses, three may be core sciences taken previously in the Division of Basic Studies (DBS), in which case released electives become available. (Released electives are courses in the natural sciences or mathematics, or engineering courses other than 205, 2611, 2612, and 2605).

The Field Program requirements are summarized as follows.

Required Courses Which May Be Taken as Core Sciences in DBS or as Field Courses in Mechanical Engineering

1031, Dynamics (DBS or Field course)

6261, Mechanical Properties of Materials (DBS)
or
3401, Materials and Manufacturing Processes (Field course)

4210, Introduction to Electrical Systems (DBS)
or
4940, Introductory Electrical Engineering (Field course)

3631, Introduction to Thermodynamics (DBS)
or
3621, Thermodynamics (Field course)

Other Required Courses

3623, Fluid Dynamics
3625, Heat Transfer and Transport Properties
3325, Mechanical Design and Analysis
3326, Systems Analysis
3053, Mechanical Engineering Laboratory

Elective Courses

A course in mathematics or mathematical methods, chosen from an approved list.

Two Field electives selected from mechanical engineering courses in the 3000 series.

Suggested Course Sequence. The following curriculum is recommended for students who enter the Field Program with only one underclass mechanical engineering course (the entry requirement of 1021, Mechanics of Solids). It may be pointed out, however, that flexibility in requirements allows many other arrangements to be made in consultation with a faculty adviser. In particular, this flexibility applies to those who have satisfied some Field requirements by taking certain engineering core sciences.

Term 5

1031, Dynamics
3621, Thermodynamics
3401, Materials and Manufacturing Processes
Mathematics Elective
Liberal Studies Elective

Term 6

3325, Mechanical Design and Analysis
3623, Fluid Mechanics
4940, Introductory Electrical Engineering
Field Elective
Liberal Studies Elective

Term 7

Engineering 3625, Heat Transfer and Transport Processes
Engineering 3326, Systems Analysis
Engineering 3053, Mechanical Engineering Laboratory
Technical Elective
Liberal Studies Elective

Term 8
Field Elective
Technical Elective
Free Elective
Free Elective
Liberal Studies Elective

Master of Engineering (Mechanical)

This degree is available as a curricular type of professional degree, the general requirements for which are stated on p. 14. Of the thirty credit hours required, the mechanical engineering program allows at least nine elective hours and offers considerable latitude in the choice of a laboratory course and the design project. In this way, it is possible to specialize in a particular area such as machine dynamics and control, mechanical analysis and development, vehicles and propulsion, propulsion engines, thermal power, thermal environment, manufacturing engineering, or material removal.

The professional degree, M.Eng. (Mechanical), may be earned in a minimum of two terms of full-time study by the successful completion of the following requirements.

Fall Term	*Hours*
Mathematics	3
3361, Advanced Mechanical Analysis	3
3090, Mechanical Engineering Design Project	3
Engineering Laboratory* or Mechanical Engineering Elective	3
Technical Elective	3
Spring Term	
Mathematics	3
3651, Advanced Thermal Science	3
3091, Mechanical Engineering Design Project	3
Mechanical Engineering Elective or Engineering Laboratory*	3
Technical Elective	3

* One Engineering Laboratory course is required, either fall or spring term.

In the curriculum outlined above, it is recommended that the mathematics requirement be satisfied by Applied Mathematics 1150–51 or, on a more advanced level, by 1180–81. Courses in the Department of Mathematics may be taken with the approval of the adviser.

The Engineering Laboratory course may be selected from Experimental Methods in Machine Design 3372 (fall) or Advanced Thermal Engineering Laboratory 3656 (either term). Qualified students may seek approval for other laboratory courses given in the College of Engineering if such courses are acceptable for a particular objective. Mechanical Engineering Design Project courses 3090 and 3091 provide design experience requiring individual effort and the preparation of a formal report. Some recent projects have been concerned with fly ash disposal, application of heat pipes to automobiles, ocean current measurement, manufacture of freeze-dried coffee, gas turbine load-test equipment, pore size measurement of plastic foam, and speed control of portable grinders. Some projects are suggested, monitored, and reviewed by outside organizations, whose engineers work with the student project groups and participate in a technical session when the project reports are presented at the end of the year.

If the six-hour mathematics requirement has been satisfied in advance by courses taken during the undergraduate years, these credit hours may be taken in elective subjects. Therefore, of the total of thirty credit hours required for the degree, at least fifteen and as many as twenty-one are elective to some degree.

Some scholarship aid is available. Admission and scholarship application forms may be obtained by writing to the Office of the Chairman, Graduate Professional Engineering Programs, 221 Carpenter Hall. Further information on the program can be obtained from the Office of the Director, Sibley School of Mechanical Engineering, 105 Upson Hall.

Master of Science and Doctor of Philosophy

These research degrees involve residence on the campus and submission of a thesis. The requirements for these degrees are described in the *Announcement of the Graduate School.*

Research studies may be undertaken in the Field of Mechanical Engineering in areas of the faculty's interest as described earlier under the Departments of Mechanical Systems and Design and of Thermal Engineering.

There is no required pattern of courses; individual programs of formal or informal study are arranged by a student in consultation with a Special Committee of his own selection.

A number of fellowships, research assistantships, and teaching assistantships are available to candidates for the M.S. and Ph.D. degrees who are doing their thesis research in the Field of Mechanical Engineering. Assistantship application forms and further information may be obtained from the Office of the Field Representative, Sibley School of Mechanical Engineering, Upson Hall.

Mechanical Systems and Design

See p. 43.

Nuclear Science and Engineering

Ward Laboratory of Nuclear Engineering

Degrees Offered: Master of Engineering (Nuclear), Master of Science, Doctor of Philosophy.

Faculty of the Engineering Field of Nuclear Engineering supervising the M.Eng. (Nuclear) degree: Messrs. K. B. Cady, D. D. Clark, T. R. Cuykendall, D. Dropkin, C. D. Gates, V. O. Kostroun, S. Linke, R. McPherson, M. S. Nelkin, R. L. Von Berg.

Faculty of the Graduate Field of Nuclear Science and Engineering supervising the Master of Science and Doctor of Philosophy degrees: the persons listed above and, in addition, Messrs. R. M. Littauer and G. H. Morrison.

Courses of instruction are listed under Applied and Engineering Physics on pp. 57–60.

Nuclear science and nuclear engineering are concerned with the understanding, development, and practical application of scientific knowledge of nuclear reactions and radiations.

The programs at Cornell are designed to accommodate students who are interested in *(a)* nuclear physics, *(b)* nuclear engineering, *(c)* radiation protection, or *(d)* some combination of these. Subjects in nuclear physics include low-energy nuclear structure, atomic structure, and phenomena involving interactions between nuclear and atomic processes. Nuclear engineering involves the basic sciences of chemistry, physics, and mathematics in combination with the skills of metallurgical, chemical, civil, electrical, and mechanical engineering—with the goal of designing safe, efficient nuclear energy systems. Radiation protection, nuclear safety, and environmental effects of nuclear energy utilization comprise a third important area of study; in addition to inclusion of these topics in the regular nuclear engineering courses, a new undergraduate course 8301, Nuclear Energy and the Environment, is now being offered, and graduate students have the opportunity to take courses in radiation biology taught in the Department of Physical Biology.

The aims of the Cornell programs are to provide the student with a thorough understanding of the scientific principles upon which nuclear systems are based, to develop the skills of applying these principles to engineering problems, and (in the M.S. and Ph.D. programs) to develop research abilities.

To implement these aims, Cornell offers three graduate degrees: a professional degree, Master of Engineering (Nuclear), administered by the Engineering Field of Nuclear Engineering, and two research degrees, Master of Science and Doctor of Philosophy, administered by the Graduate Field of Nuclear Science and Engineering. At the undergraduate level, a student can enroll in the College Program and take a major in *nuclear engineering* or take a sequence of courses in the area of *energy conversion.*

Appropriate undergraduate programs which can lead to graduate study in nuclear science and engineering are physics, engineering physics, or civil, chemical, electrical, mechanical, or materials engineering, or a suitable set of courses in the College Program. Students should select their technical electives carefully to ensure that they meet the entrance requirements for the graduate program they intend to enter.

Laboratory and Research Facilities

The Ward Laboratory of Nuclear Engineering contains: (1) A TRIGA research reactor with a steady-state power of 100 kilowatts and a pulsing capability of 250 megawatts providing sources of neutrons and gamma rays for activation analysis, solid and liquid state studies, and nuclear physics research. In addition to standard pneumatic and mechanical transfer systems for activated specimens, the reactor is equipped with a 50 millisecond rapid transfer mechanism in one of the six beam ports; (2) a critical facility or "zero power reactor" of versatile design for basic studies of reactor physics, such as space-dependent reactor kinetics and noise analysis; (3) a 3 MeV positive-ion accelerator for studies of radiation effects and low energy nuclear levels and reactions; (4) a shielded cell with 5,000 curies of Co^{60} gamma source for radiation chemistry studies; (5) a radiochemistry laboratory; and (6) subcritical assemblies for reactor physics investigations.

The Degree Programs

Undergraduate College Programs

Students are encouraged to begin specialization in nuclear science and engineering at the undergraduate level. This can be done by selection of appropriate courses with the approval of the College Program Committee.

Major in Nuclear Engineering. A student majoring in nuclear engineering under the College Program would take Nuclear Energy and the Environment (8301) and Introduction to Nuclear Science (8303). Also required would be two of the following courses: Nuclear Reactor Theory I (8312), Nuclear Measurements Laboratory (8351), Nuclear Reactor Engineering (8333), and Low Energy Nuclear Physics (8309).

College Program in Energy Conversion. This program is a synthesis of nuclear, thermal, and electrical engineering and is described in the College Program section of this Announcement; see p. 33.

Master of Engineering (Nuclear)

This two-term curriculum 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. There is a growing need in the nuclear industry and the regulatory agencies for engineers who have a thorough knowledge of these safety provisions and who are able to apply it to the design of reactor plants and auxiliary equipment and to the implementation of environmental monitoring systems. Required courses in the Master of Engineering (Nuclear) program treat reactor safety and radiation protection and control in depth, and an elective course in radiation biology and an elective seminar in physical biology are available.

The background recommended for the M.Eng. (Nuclear) degree program includes: (1) a baccalaureate degree in engineering, physics, or applied science; (2) modern 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.

The interdisciplinary nature of nuclear engineering allows students to enter from a variety of undergraduate specializations. Our students in the past have had widely varying background preparations including physics, engineering physics, mechanical engineering, chemical engineering, electrical engineering, civil engineering, materials science and engineering, and nuclear engineering.

The thirty credit hours for the degree include the following courses:

Fall Term
8312, Nuclear Reactor Theory I
8333, Nuclear Reactor Engineering
Technical Elective
Mathematics or Physics Elective

Spring Term
8351, Nuclear Measurements Laboratory
8309, Low Energy Nuclear Physics
Technical Elective
Engineering Design Project

The 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. Typical examples of courses that might be chosen by Master of Engineering (Nuclear) degree candidates are: Biological Effects of Radiation (Physical Biology 922), Elements of Physical Biology (Physical Biology 920), Energy Conversion (3672), Convection Heat Transfer (3680), Applications of Fluid Mechanics (3676), Introduction to Plasma Physics (4561), Advanced Plasma Physics (4564), Introductory Plasma Physics (7201), Introductory Magnetohydrodynamics (7202), and Feedback Control Systems (4481–82).

Admission and scholarship application forms may be obtained by writing to the Office of the Chairman, Graduate Professional Engineering Programs, 221 Carpenter Hall. Further information on the nuclear professional program may be obtained by writing to the Ward Laboratory of Nuclear Engineering.

Master of Science and Doctor of Philosophy

The M.S. and Ph.D. programs are oriented toward research, and require completion of a thesis as well as course work. A candidate for one of these degrees chooses either *nuclear science* or *nuclear engineering* as his major subject, but because each student plans an individual program in consultation with the faculty members of his Special Committee, there are no detailed course requirements. This approach, long a tradition of graduate study at Cornell, is well suited to interdisciplinary fields such as nuclear science and engineering. Independent thesis research along with formal and informal discussions with staff members and other students is a vital part of the program.

If a student chooses *nuclear science* as his major subject, thesis research may be undertaken in any of the following areas: nuclear structure physics, atomic physics and x-ray phenomena, nuclear astrophysics, nuclear chemistry, nuclear instrumentation, radiation chemistry, and radiation effects on materials. If he selects *nuclear engineering*, the following areas are possible: experimental and analytical reactor physics, reactor plant dynamics and safety, radiation protection and control, neutron transport theory and kinetic theory, nuclear energy conversion, nuclear environmental engineering, and nuclear structural engineering.

The appropriate preparation for graduate work in these programs is an undergraduate education in science, applied science, or engineering, with special emphasis on mathematics and modern physics.

Additional information on the M.S. and Ph.D. programs is available in the *Announcement of the Graduate School.* Further information may be obtained from the Office of the Graduate Field Representative, Ward Laboratory of Nuclear Engineering.

Operations Research

Upson Hall

Degrees Offered: Master of Science, Doctor of Philosophy. The School of Industrial Engineering and Operations Research administers the undergraduate Field of Industrial Engineering and Operations Research and the Master of Engineering (Industrial) degree program (see pp. 39–40).

Mr. R. E. Bechhofer, chairman; Messrs. L. J. Billera, M. Brown, R. W. Conway, M. J. Eisner, H. Emmons, D. R. Fulkerson, H. P. Goode, J. C. Kiefer, W. F. Lucas, W. R. Lynn, W. L. Maxwell, H. L. Morgan, G. L. Nemhauser, N. U. Prabhu, S. Saltzman, B. W. Saunders, A. Schultz, Jr., F. L. Spitzer, S. Stidham, Jr., H. M. Taylor 3d, L. I. Weiss. Visiting staff: Mr. C. R. Glassey.

Courses of instruction are listed on pp. 85–89.

The Field of Operations Research offers doctoral programs in four major subjects: operations research, applied probability and statistics, systems analysis and design, and industrial engineering. Master of Science programs are offered in all the above subjects, as well as in information processing.

A general description of the five subjects is given below.

Operations Research

The problem areas and techniques of operations research are approached from a highly analytical viewpoint. Emphasis is placed on constructing appropriate mathematical models to represent various real-life operational systems, and on developing techniques for analyzing the performance of these models. In this way procedures with desirable properties for dealing with such systems are developed. Queuing, inventory, reliability, replacement, and scheduling theories and simulation are employed. Optimization techniques such as mathematical programming (linear, nonlinear, and probabilistic), network flows, combinatorics, and dynamic programming are also used extensively, as are the various techniques of the mathematical theory of games.

The operations research student pursues a course of study and research that emphasizes the use of the mathematical, probabilistic, statistical, and computational sciences in the development of the techniques of operations research. His ultimate goal may range from making a fundamental contribution to the techniques of operations research to applying these techniques to problems in diverse professional fields.

Applied Probability and Statistics

This subject of study and research is designed for students having primary interests in the techniques and associated underlying theory of probability and statistics, particularly as they are applied to problems arising in science and engineering. The techniques emphasized are those associated with applied stochastic processes (for example, queuing theory, traffic theory, inventory theory, and time-series analysis) and statistics (including statistical decision theory; the statistical aspects of the design, analysis, and interpretation of experiments, and of ranking and selection theory; reliability theory; statistical quality control; sampling inspection; and acceptance sampling).

Students who elect work in this area are expected to acquire considerable knowledge of the theory of probability and statistics. All students who major in applied probability and statistics are required to minor in mathematics.

Systems Analysis and Design

Although the solution of systems problems requires knowledge of underlying theory, the inherent practical limitations of the problem must be understood. Analysis of a system alone is insufficient; alternative solutions must be generated before selection of the one which can best be integrated with other elements of the system. Modeling concepts are equally important, but only when they can produce workable systems. Illustrations of the design of integrated systems can be found in industry, the environment, commerce, and government. A good example is the design of urban traffic control systems. Research activity may involve the development of new methodology or the synthesizing of new combinations from what is already known. The goal is to improve the understanding of systems or to develop new decision criteria for systems.

Industrial Engineering

Studies of the analysis and design of the complex operational systems that occur in industry, particularly in manufacturing, are included in this subject. Plant design, cost analysis and control, and production planning are some of the major topics. A student is expected to have considerable facility in the modern analytical techniques associated with rational decision making and the establishment of valid design criteria. These techniques are drawn from among inventory theory, queuing theory, mathematical programming, quality control, and computer simulation.

Because the design and operation of modern engineering systems apply to areas other than manufacturing, the use of the word "industrial" should not be considered restrictive. Industrial engineers frequently are employed as systems specialists in commerce, banking, distribution, merchandising, and hospital management.

Information Processing

Information processing deals with the analysis and design of systems which record, transmit, store, and process information. Emphasis is on the application and integration of equipment rather than on the design of machines. Areas of interest include systems for information retrieval, manufacturing control, and traffic control. This subject also includes such underlying theoretical topics as data structure, operating system organization, and computing language structure.

The principal campus computing facility is an IBM 360/65, with on-line operation from many campus locations. A satellite 360/20, directly connected to the 360/65, is located in Upson Hall, where the Department of Operations Research is housed. Teletypewriter terminals are also in use.

The Degree Programs

Master of Science and Doctor of Philosophy

These degree programs, administered by the Graduate School of the University, are described in the *Announcement of the Graduate School.*

Major and minor subjects are chosen from those areas outlined above. Minors can also be subjects offered by other units of the University; appropriate minors that have been chosen most frequently in recent years, and the departments or schools which offer courses of study in them are: applied mathematics (Applied Mathematics), computer science (Computer Science), econometrics and economic statistics (Economics), public systems planning and analysis (Civil and Environmental Engineering), managerial economics (Business and Public Administration), mathematics (Mathematics), and planning theory and systems analysis (City and Regional Planning).

A prerequisite for graduate study in the Field of Operations Research is a Bachelor's degree in engineering, mathematics, economics, or the physical sciences, awarded by an institution of recognized standing. The candidate must have a commendable undergraduate scholastic record and must supply other evidence of his interest in and ability to pursue advanced study and research in his proposed major and minor subjects. Submission of the results of the Graduate Record Examination is strongly recommended for all applicants and is required for fellowship and assistantship applicants.

Further information, including a brochure, *Operations Research at Cornell,* may be obtained by writing to the Office of the Graduate Field Representative, Department of Operations Research, Upson Hall.

Structural Engineering

See p. 30.

Theoretical and Applied Mechanics

Thurston Hall

Degrees Offered: Master of Engineering (Engineering Mechanics), Master of Science, Doctor of Philosophy.

Mr. B. A. Boley, chairman; Messrs. K. T. Alfriend, H. D. Block, J. A. Burns, H. D. Conway, E. T. Cranch, J. C. Dunn, R. H. Lance, G. S. S. Ludford, Y. H. Pao, R. H. Rand, D. N. Robinson, W. H. Sachse. Visiting staff: Messrs. A. Jahanshahi, J. T. Jenkins.

Courses of instruction are listed on pp. 97–100.

The Department of Theoretical and Applied Mechanics is responsible for undergraduate and graduate instruction and research in theoretical and applied mechanics and applied mathematics. The subject matter in these fields is of a fundamental nature, and the undergraduate courses provide a substantial part of the basic engineering science education for engineering students. In addition to the required core courses, the undergraduate can elect advanced courses which are especially suited to students who have demonstrated superior analytical or experimental ability and who wish to extend and develop this ability. The Department offers undergraduate programs in individualized major and minor subjects through the College Program described below and on p. 32.

The Degree Programs

The Undergraduate College Program

The Department sponsors an undergraduate College Program in Engineering Science that has a science-based curriculum flexible enough to be adapted to special or developing interests. It is designed for engineering students who want flexibility in their undergraduate curricula; for students whose interests are not reflected by any of the major engineering disciplines; for students who want to emphasize basic engineering sciences; and for those who want to postpone specialization.

There are general guidelines for the curriculum, but no specific prescribed courses beyond those required of all engineering students during their first two years in the Division of Basic Studies. The idea is to develop a solid understanding of the basic science behind all engineering, and to supplement this with study in a particular area, such as astronomy, applied mathematics, physics, chemistry, or biology. A typical program is shown on page 32.

Any faculty member of the Department of Theoretical and Applied Mechanics can sponsor an individual student who wishes to plan a College Program in Engineering Science. The choice of particular courses is based on the educational goals of the student, and is made jointly by the student and his adviser.

It should be noted that this is a College-approved curriculum equivalent to a Field Program. It provides the opportunity for choice of professional specialization within a sound, science-based curriculum, and it offers maximum flexibility in curriculum, since there are no specifically required courses. Further information may be obtained from faculty members of the Department.

Master of Engineering (Engineering Mechanics)

Students interested in advanced study in mechanics and who intend to emphasize engineering practice rather than teaching or research may apply for admission to the M.Eng. (Engineering Mechanics) degree program. This course of study is designed to allow the student to master advanced topics in mechanics and, at the same time, to develop his facility in applying fundamental concepts in mechanics to modern engineering problems. No formal thesis is required for this degree; however, the student is required to carry out an individual project, either analytical or experimental in nature, under the supervision of a faculty member.

Admission requirements are: (1) a baccalaureate degree in engineering or applied science; and (2) a cumulative grade-point average of at least 2.5 (see p. 12) in the undergraduate curriculum. Undergraduate programs of non-Cornellians must, in the judgment of faculty members in the Field, show adequate preparation in mechanics.

Degree requirements are: (1) completion of a minimum of three credit hours of work on an individual project under the direction of a faculty member; (2) satisfactory completion of six credit hours of course work in mathematics or applied mathematics (which may be satisfied by the Theoretical and Applied Mechanics course sequence 1180–81 or the equivalent); and (3) courses in or relating to theoretical and applied mechanics, selected in consultation with the student's adviser from those offered at the graduate level, to bring the total credit hours to at least thirty.

A general description of the Master of Engineering degree is given on p. 10. Further information may be obtained from members of the Department.

Master of Science and Doctor of Philosophy

These research-oriented degrees, administered by the Graduate School of the University, require submission of a thesis. A description is given in the *Announcement of the Graduate School.*

The graduate program in mechanics and applied mathematics emphasizes fundamental understanding of the newest developments in engineering and applied science. The basic nature of the studies encourages research that cuts across and extends various traditional engineering fields and ensures that the specialist will find many opportunities to work, either in industry or in academic institutions, on advanced engineering projects for which conventional training is often inadequate.

Graduate students may pursue programs involving theoretical or experimental work in the following areas of specialization.

1. Space mechanics, including research on trajectories and orbits of space vehicles and satellites and on the theory of light-weight, thin-walled structures.

2. Wave propagation in solids, waves in layered media; scattering of elastic waves and dynamic stress concentrations; waves in plates, rods, and shells.

3. Structural mechanics, including the mechanics of composite materials, static and dynamic loadings; linear and nonlinear vibrations and buckling.

4. Theory of elasticity, inelasticity, and plasticity, including the effects of high-temperature environment.

5. Experimental mechanics—experimental facilities are available for research in many areas of study, including linear and nonlinear vibrations, wave propagation and damping measurements in solids, mechanical behavior of composite materials, magnetoelasticity, and photoelasticity.

6. Continuum mechanics.

7. Biomechanics and bionics, artificial intelligence and robots.

8. Theoretical fluid mechanics, with research in gasdynamics and magnetohydrodynamics.

The flexibility of the graduate study programs at Cornell permits students to draw on several divisions of the University for supporting work in pure and applied science. Graduate students interested primarily in theoretical and applied mechanics and applied mathematics find these supporting fields of interest: mathematics, structures, engineering physics, servomechanisms, machine design, aerospace engineering, soil mechanics, and physics.

A brochure, *Theoretical and Applied Mechanics at Cornell,* can be obtained by writing to the Office of the Graduate Field Representative, Theoretical and Applied Mechanics, Thurston Hall.

Thermal Engineering

See p. 43.

University Program on Science, Technology, and Society

Mr. F. A. Long, director; Mr. R. Bowers, deputy director; Mr. P. Bereano, executive secretary.

Students and faculty members from all parts of the University are welcome to participate in the interdisciplinary Program on Science, Technology, and Society. The purpose of STS is to stimulate and initiate teaching and research on the interaction of science and technology with contemporary society and also to provide coherence and support for current University activities in this area.

Topics of concern to the Program are illustrated by the following examples: science, technology, and national defense; world population and food resources; legal and moral implications of modern biology and medicine; national policy for the development of science; sociology of science; and the ecological impact of developing technology. Mechanisms for studying problems such as these include courses, seminars, short workshops, and individual research programs.

The following courses are cosponsored by STS in collaboration with other units of the University.

Applied Physics 8901, Issues and Methods in Applying Science. Fall term. Mr. Webb.

Biology 201–202, Biology and Society. Fall and spring terms. Mr. Zahler.

Biology 203–204, Special Topics in Social Biology. Fall and spring terms. Mr. Zahler.

Business and Public Administration 461, Biomedical Research and Development and the Delivery of Health Services. Fall term. Mr. Rettig.

Business and Public Administration 559, Science, Technology, and Public Policy. Spring term. Mr. Rettig.

Center for Research in Education 350, Ecological Thought: History, Consequences, and Prospects. Fall term. Messrs. Eisner, Provine, Bickel, and Jutro.

Computer Science 305, The Computerized Society. Fall term. Mr. Horowitz and Mrs. Horowitz.

Economics 302, The Impact and Control of Technological Change. Spring term. Mr. Mueller and Mrs. Nelkin.

Engineering 205, Social Implications of Technology. Fall term. Mr. Nelkin.

Engineering 2605, The Law and Environmental Control. Fall term. Mr. Bereano.

Engineering 2606, Technology Assessment. Spring term. Mr. Bereano and Mr. Bowers.

Government, Business and Public Administration, and Center for International Studies 561, Transfers of Science and Technology from Industrialized to Developing Countries. Fall term. Mr. Esman.

A list of other relevant courses may be obtained from the Program Office, 628 Clark Hall.

Description of Courses

Course descriptions are listed under the school, department, or division in which they are offered. Certain humanities, mathematics, and physical science courses are listed under Basic Studies, even though they are offered by the College of Arts and Sciences. For more complete listings in humanities, social sciences and natural sciences, consult the *Announcement of the College of Arts and Sciences.*

Each course title is followed by a (u) or (g) designation to indicate the level at which the course is taught. The (u) designation means that the course is intended primarily for undergraduates; the (g), for graduates. In many instances, both undergraduates and graduates are welcome in particular courses if they meet the prerequisites. Undergraduates should consult their school or department advisers concerning eligibility for courses with graduate designations.

Descriptions of courses will be found in this section of the Announcement, *arranged alphabetically according to school or department following the Basic Studies Division. The course numbers have significance as follows:*

Three-digit numbers
Agricultural Engineering
Basic Studies
Computer Science
Geological Sciences

1000–1999
Theoretical and Applied Mechanics

2000–2999
Civil and Environmental Engineering

3000–3999
Mechanical Engineering
3300, 3400 Mechanical Systems and Design
3600 Thermal Engineering

4000–4999
Electrical Engineering

5000–5999
Chemical Engineering

6000–6999
Materials Science and Engineering

7000–7999
Aerospace Engineering

8000–8999
Applied and Engineering Physics

9000–9999
Industrial Engineering and Operations Research

Basic Studies Division

105 Elements of Engineering Communication (u). Either term. Credit three hours. One lecture, one recitation, one laboratory.
Communication of physical concepts to others; communication with digital computers. Principles of graphics and computer programming studied through projects related to design and modeling of physical processes. Graphics emphasizes sketching to develop skill in visual communication.

106 Engineering Perspectives (u). Either term. Credit three hours. One lecture, one recitation, one laboratory.
Illustration of engineering point of view through detailed study of specific problems with major engineering aspects. Students choose "mini-courses" from selection offered by various faculty members throughout the College of Engineering. Small recitations and work sessions to permit close contact between students and engineering faculty. Lectures will present an overview of the engineering profession.

Mathematics

191 Calculus for Engineers (u). Either term. Credit four hours. Prerequisite: *three* years of high school mathematics, including trigonometry. Fall term: lectures, M W F 9:05, 11:15 plus recitation periods to be arranged. Spring term: M W F S 9:05, 11:15. Preliminary examinations will be held at 7:30 p.m. on Oct. 1, Oct. 22, Nov. 12, Dec. 3.
Plane analytic geometry, differential and integral calculus, and applications.

192 Calculus for Engineers (u). Either term. Credit four hours. Prerequisite: 191 or 193. Lectures, M W F 9:05, 11:15 plus recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. on Oct. 1, Oct. 22, Nov. 12, Dec. 3, Feb. 16, Mar. 8, Apr. 5, May 3.
Transcendental functions, technique of integration and multiple integrals, vector calculus, analytic geometry in space, partial differentiation, applications.

193 Calculus for Engineers (u). Fall. Credit four hours. Prerequisite: *four* years of high school mathematics, including trigonometry and calculus. Lectures, M W F 9:05, 11:15 plus recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. on Oct. 1, Oct. 22, Nov. 12, Dec. 3.
Covers contents of 191 in more detail and includes more theoretical material.

194 Calculus for Engineers (u). Spring. Credit four hours. Prerequisite: recommendation of the lecturer in course 191 or 193. Lectures, M W F 9:05, 11:15 plus recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. on Feb. 16, Mar. 8, Apr. 5, May 3.
Covers contents of 192 in more detail and includes more theoretical material.

293–293H Engineering Mathematics (u). Either term. Credit four hours. Prerequisite: 192 or 194. Lectures, M W F 10:10, 12:20 plus recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. on Oct. 12, Nov. 9, Dec. 7; Feb. 29, Mar. 21, May 2. 293H is an Honors section given in the fall term only.
Vectors and matrices, first-order differential equations, infinite series, complex numbers, applications. Problems for programming and running on the automatic computer will be assigned, and students are expected to have a knowledge of computer programming equivalent to that taught in Engineering 105.

294–294H Engineering Mathematics (u). Either term. Credit three hours. Prerequisite: 293. Lectures, M W 8, 12:20 plus recitation periods to be arranged. Preliminary examinations will be held at 7:30 p.m. on Oct. 5, Nov. 2, Nov. 30, Feb. 22, Mar. 14, Apr. 24. 294H is an Honors section given in the spring term only.
Linear differential equations, quadratic forms and eigenvalues, differential vector calculus, applications.

Physics

112 Physics I: Introductory Analytical Physics (u). Either term. Credit four hours. Prerequisite: coregistration in Mathematics 192 (or 112). Lecture, M 10:10 or 12:20. Three discussion periods per week and one two-hour laboratory period every other week to be arranged. Preliminary examinations will be held at 7:30 p.m. Oct. 5, Nov. 9, Feb. 22, Apr. 11. Primarily for students of engineering and for prospective majors in physics. Fall term, Messrs. Ashcroft, Hartill, and staff. Spring term, Mr. Silcox and staff.
The mechanics of particles: kinematics, dynamics, conservation of linear momentum, central-force fields, conservation of energy, periodic motion. The mechanics of many-particle systems: center of mass, angular momentum of a rigid body, simple rotational mechanics of a rigid body. Introduction to special relativity: invariance of velocity of light, Lorentz transformation, relativistic momentum and energy. At the level of *Mechanics and Heat* by Young.

213 Physics II: Electricity and Magnetism (u). Spring. Credit three hours. Primarily for students of engineering and for prospective majors in physics. Prerequisite: Physics 112 and Mathematics 191, 193, or 112. Coregistration in 213L required. Lectures, T Th 9:05 or 11:15. Two discussion periods per week to be arranged. Preliminary examinations will be held at 7:30 p.m. on Oct. 12, Nov. 23; Feb. 29, Apr. 11. Mr. Pohl and staff.
Electrostatics, behavior of matter in electric fields, magnetic fields, Faraday's Law, electromagnetic oscillations and waves, magnetism and relativity. At the level of *Fundamentals of Electricity and Magnetism* 1969, by Arthur F. Kip.

213L Laboratory to Accompany Physics 213 (u). Either term. Credit one hour. Coregistration in Physics 213 required. One two-hour period every week to be arranged.
Experiments include electrical measurements and circuits, and physical electronics.

214 Physics III: Optics, Waves, and Particles (u). Either term. Credit three hours. Primarily for students of engineering and for prospective majors in physics. Prerequisite: Physics 213 and Mathematics 192 or 221; coregistration in 214L required. Lectures, T Th 9:05 or 11:15. Two discussion periods per week to be arranged.
Wave phenomena; electromagnetic waves; physical and geometrical optics; quantum effects, matter waves; uncertainty principles; introduction to wave mechanics, elementary applications. At the level of *Fundamentals of Optics and Modern Physics* by H. D. Young.

214L Laboratory to Accompany Physics 214 (u). Either term. Credit one hour. Coregistration in Physics 214 required. One two-hour period to be arranged.
Experiments include optics, lasers, atomic spectroscopy, solid state, nuclear, and particle physics.

217 Physics II: Electricity and Magnetism (u). Fall. Credit three hours. An Honors section of 213. Prerequisite: the same as for 213; in addition: *(a)* a request for this course as expressed by the student in consultation with the instructor, and for an engineering student the concurrence of the director of the Division of Basic Studies in the College of Engineering; *(b)* an invitation from the instructor. Enrollment limited. T Th S 11:15.
Topics included are the same as in Physics 213, but their treatment is generally more analytical and somewhat more intensive.

218 Physics III: Optics, Waves, and Particles (u). Spring. Credit three hours. An Honors section of 214. Same conditions as for course 217 govern enrollment. T Th S 11:15.

218L Laboratory to Accompany Physics 218 (u). Spring. Credit one hour. May be taken without 218 by permission of the instructor. One two-hour period every week to be arranged.
Experiments include optics, lasers, atomic spectroscopy, solid state, nuclear, and particle physics.

Chemistry

107–108 General Chemistry (u). Throughout the year. Credit: fall term, three hours; spring term, four hours. Enrollment limited. Recommended for those students who will take further courses in chemistry. Prerequisite: high school chemistry; 107 is prerequisite to 108. Lectures, T Th 9:05, 10:10, or 12:20. Laboratory, T Th or F 8–11; M T W Th or F 1:25–4:25. Spring term, one additional recitation hour to be arranged. Fall term, Messrs. Kostiner and Scholer and assistants. Fall term preliminary examinations will be held at 7:30 p.m. on Oct. 7 and Nov. 11. Spring term, Mr. Sienko and assistants. Preliminary examinations will be held in the evening.
The important chemical principles and facts are covered, with considerable attention given to the quantitative aspects and to the techniques that are important for further work in chemistry. Second-term laboratory includes a systematic study of qualitative analysis.

Note: Entering students exceptionally well prepared in chemistry may receive advanced placement credit for Chemistry 107–108 by demonstrating competence in the Advanced Placement Examination of the College Entrance Examination Board or in the departmental examination given at Ithaca on the Saturday before classes start in the fall.

Engineering Sciences

Group I

9160 Introductory Engineering Probability (u). Both terms. Credit three hours. Three lectures. Prerequisite: first year calculus. Messrs. Billera, Emmons, and Weiss.
At the end of this course a student should have a working knowledge of some of the basic tools in probability theory and their use in engineering. This course may be the last course in probability for some students or it may be followed by a course in statistics. The topics that are introduced include: a definition of probability; basic rules for calculating with probabilities when the number of possible outcomes is finite; discrete and continuous random variables; probability distribution and density functions; expected values, jointly distributed random variables, and marginal and conditional distributions; special distributions important in engineering work: the normal, exponential, binomial, Poisson, and other distributions and how they arise in practice; and Markov chains and applications.

9170 Basic Engineering Statistics (u). Both terms. Credit three hours. Two lectures, one recitation. Prerequisite: first year calculus. Messrs. Taylor and Brown.
At the end of this course a student should command a working knowledge of basic statistics as it applies to engineering work. For many students this will be the only course in statistics they will ever take. For students who wish to learn more about statistics, a course in probability (e.g., 9160) is recommended. The topics are: graphical and numerical means of representing data—histograms and cumulative frequency polygons, sample means and variances; basic tools of probability, discrete and continuous random variables, probability distribution and density functions, expected values and "population" moments, special distributions—the normal, chi-square, binomial and others; tests of "significance" and one- and two-sided hypothesis tests concerning the mean of a normal distribution when the standard deviation is known (unknown); hypothesis tests concerning the variance of a normal distribution; point- and confidence-interval estimation; correlation and curve fitting by least squares.

202 Computers and Programming (u). Either term. Credit three hours. Prerequisite: some programming experience in an algebraic language. M W 9:05 or T Th 10:10. Laboratory, M W Th or F 2:30–4:25.
Intended as a foundations course in computer programming and machine organization. Algorithms and their relation to computers and programs. A procedure-oriented language: specification of syntax and semantics, data types and structure, statement types, program structure. Machine organization: components, representation of data, storage addressing, instructions, interpretation cycle, interrupts. Assembly language programming: format and basic instructions, the assembly process, loops and indexing, data types, subroutines, macros. Programming and debugging problems on a computer are essential parts of this course.

Group II

4210 Introduction to Electrical Systems (u). Either term. Credit three hours. Three lecture-recitations. Prerequisites: Mathematics 192 and Physics 112. Mr. McIsaac and staff.
A course intended to develop competence in several analysis skills appropriate to the field of electrical engineering and to impart understanding of the physical basis for the concepts associated with the skills. Topics include: electrical circuit elements (resistors, capacitors, inductors, independent sources, and branch relationships); time functions and their representation (real exponentials, complex numbers, trigonometric functions, and complex exponentials); response of simple networks and the impedance concept (natural response, forced response to periodic excitation and pole-zero concepts); circuit equations and methods of solution (branch equations, Kirchhoff's laws, nodal and mesh equations, matrix methods of solution, and Norton and Thevenin equivalents); controlled sources and modeling of devices (representation of idealized electronic and electromechanical devices).

6262 Electrical Properties of Materials (u). Spring. Credit three hours. Two lectures and one recitation or laboratory.
Description and understanding of physical properties and applications of electrical materials. Electronic structure of atoms, molecules, and crystalline solids. Energy band concept applied to insulators, semiconductors, and metals. Semiconductors and applications in electronic devices. Thermoelectricity, dielectrics, and magnetic properties.

8117 Contemporary Topics in Applied Physics (u). Spring. Credit three hours. The course will consist of lecture periods combined with recitations and some experiments. Staff.
Selected examples of contemporary applications of modern physics will be studied. The objective is to develop a semiquantitative understanding of the underlying physical principles and phenomena and the intrinsic limits they place on applications. Discussion will also include the interplay between physics and other factors (technological, scientific and, when relevant, social and political) which set limits on application of modern physics and influence its development. For example, lasers of different types will be analyzed and their limitations discussed in terms of energy levels, lifetimes of states, and other concepts of atomic physics, plus the limitations on laser development imposed by materials properties. Nuclear energy utilization will be studied in terms of the physics of fission, fusion, and plasmas, along with the technological and social factors affecting development of nuclear energy sources. Selected solid state devices will serve to illustrate the concepts of band structure and electron transport. Applications of physics in other sciences such as astrophysics and biology may also be included.

Group III

1001 Introduction to Applied Mechanics (u). Fall and spring. Credit three hours. One lecture, two recitations; demonstration laboratory four times per term. Prerequisite: registration in Mathematics 293.
Introduction to technical theory of mechanical behavior of rigid and deformable solids. Principles of mechanics, statics, dynamics. Kinematics and kinetics of a particle, a system of particles, and a rigid body. Methods of analysis including energy and momentum. Mechanics of deformable solids. Kinematics and strain, forces and stress, the constitutive relation.

Elasticity, plasticity, viscoelasticity. Rods, beams, tubes, stresses, and deformations. At the level of *Introduction to Engineering Mechanics* by Huddleston.

1021 Mechanics of Solids (u). Fall and spring. Credit three hours. Two lectures, one recitation; demonstration laboratory four times per term. Prerequisite: registration in Mathematics 293.
Principles of statics, force systems, and equilibrium. Mechanics of deformable solids, stress, strain, statically determinate and indeterminate problems. Analysis of slender bars, shearing force, bending moment, singularity functions. Plane stress, transformation of stress, Mohr's circle of stress and strain. Stress-strain-time-temperature relations, elasticity, plasticity, viscoelasticity. Bending and torsion of slender bars, stresses, deformations, and plastic behavior. Virtual work, energy methods, and applications. At the level of *An Introduction to the Mechanics of Solids* by Crandall and Dahl.

1031 Dynamics (u). Fall and spring. Credit three hours. Two lectures, one recitation; demonstration laboratory four times per term. Prerequisite: registration in Mathematics 293.
Principles of Newtonian dynamics of a particle, systems of particles, and a rigid body. Kinematics, frames of reference, motion relative to a moving frame, impulse, momentum, energy. Laws of motion of a system, center of mass, total kinetic energy, moment of momentum, constraints. Rigid body kinematics, angular velocity, moment of momentum and the inertia tensor, Euler equations, the gyroscope. Advanced methods in dynamics. Generalized coordinates, Lagrange's equations, the potential energy function, the kinetic energy function, applications. At the level of *Applied Mechanics-Dynamics* by Housner and Hudson.

6261 Mechanical Properties of Materials (u). Either term. Credit three hours. Two lectures, one recitation or laboratory.
Elastic, anelastic, and plastic behavior of crystalline and rubber-like materials, single and polycrystalline materials. Stress-thinning mechanisms, composite materials; fracture, fatigue, and creep. Crystal structure, lattice defects, phase equilibria, diffusion, macrostructure and microstructure from programmed learning sequences. Engineering applications of materials.

Group IV

(Several courses in physical and organic chemistry offered by the Department of Chemistry in the College of Arts and Sciences at Cornell qualify as engineering core sciences in the chemistry area.)

3631 Introduction to Thermodynamics (u). Fall and spring. Credit three hours. Three recitations. Prerequisite: Mathematics 191 and 192, Physics 112 and 213.
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.

5101 Mass and Energy Balances (u). Fall and spring. Credit three hours. Three lectures, one computing session. Mr. Thorpe.
Engineering problems involving material and energy balances. Flow-sheet systems and balances. Total energy balances and flow systems.

Aerospace Engineering

7001 Introduction to Aeronautics (u,g). Fall. Credit three hours. Open to upperclass engineers and others by permission of the instructor. Mr. Sears.
An introduction to atmospheric flight vehicles. Principles of incompressible and compressible aerodynamics, boundary layers, and wing theory. Propulsion systems, including analysis of engine types, propellers, fans, and rotors. Aircraft performance: maximum speed, rate of climb, range and endurance, takeoff and landing. Turning performance. Maneuver and gust loads. Elements of stability and control.

7002 Introduction to Aerospace Systems (u,g). Spring. Credit three hours. Mr. Auer.
Various topics will be treated from the following list: mechanics of trajectories and orbits; propulsion systems, including chemical, nuclear, and advanced; guidance, tracking, and communication systems; the problem of reentry; life support. Applications to be discussed will include missiles, communication and navigation satellites, geology, cislunar probes, lunar and planetary exploration, and deep space probes.

7003 Introduction to Geophysics (u,g). Fall. Credit three hours. Open to upperclass engineers, majors in the physical sciences, and others by permission of the instructor. Mr. Turcotte.
Rotation and figure of the earth, gravitational field, seismology, geomagnetism, creep and anelasticity, radioactivity, earth's internal heat, continental drift, and mantle convection. Text: *Physics of the Earth* by F. D. Stacey.

7101 Applied Thermal Physics (g). Fall. Credit three hours. Mr. Resler.
Classical thermodynamics, kinetic theory and statistical mechanics applied to selected areas of research such as high temperature gas reactions, gas lasers, and ferromagnetism. Some previous experience with thermodynamics is desirable. Topics covered are flexible, depending on class interest.

7102 Gasdynamics (g). Spring. Credit three hours. Mr. Resler.
Strong shock waves and their use in the production and study of high-temperature gases. High-temperature chemical kinetics and its application to hypersonic external flows, rocket internal flows, and other phenomena of current interest. Chemical relaxation effects of flow fields and the method of characteristics including chemical reactions. Experimental techniques.

[**7103 Dynamics of Rarefied Gases (g).** Spring. Credit three hours. Prerequisite: 7101. Not offered in 1971–72.
Flow regimes according to the Knudsen number. Theories of the shock structure at high Mach numbers. Boundary conditions at a solid wall. Slip-flow conditions. Free-molecule flows. Eigen function expansion of the linearized Boltzmann equation. Full-range and half-range moment methods. The model equation approach and recent developments for handling the transition regime.]

7104 Advanced Topics in High Temperature Gasdynamics (g). Either term. Credit three hours. Prerequisite: consent of instructor.
Topics of current importance in engineering and research. Topics included in course content may be one to three of the following. *(a)* The physics of lasers: inversions; types of lasers; theory of vibrational energy transfer in gases; optics of lasers; review of laser applications. *(b)* Electro-fluid dynamics, with

emphasis on the theory of electric probes: free molecular probes, sheath formation, effect of potential outside sheath, flow effects; stagnation point and flush probes. *(c)* Molecular collision cross sections: quantum mechanical methods; Born approximation; Born-Oppenheimer approximation; method of distorted waves; Gryzinski's semi-classical method. *(d)* Molecular relaxation phenomena: rotational and vibrational relaxation; relaxation of a system of harmonic oscillations; dissociation processes; vibration-dissociation interaction; ionization processes. *(e)* Ionic and electronic mobility: relation to cross sections; dependence on electric field and on temperature; effect of inelastic collisions; electron mobility at high degrees of ionization.

7201 Introductory Plasma Physics (g). Fall. Credit three hours. Mr. Auer.
Intended to be a first course in plasma physics and includes: plasma state, particle orbits in electric and magnetic fields, adiabatic invariants, Coulomb scattering, transport phenomena, plasma oscillations and waves, hydromagnetic equations, energy principle and instabilities, applications to laboratory and space plasmas, introduction to controlled thermonuclear research. At the level of *Elementary Plasma Physics* by Longmire.

7202 Introductory Magnetohydrodynamics (g). Spring. Credit three hours. Mr. Turcotte.
Basic equations of magnetohydrodynamics. Flow problems. Hydromagnetic shock waves. The pinch effect and instabilities. Tensor conductivity and excess electron temperature.

[**7203 Intermediate Plasma Physics (g).** Spring. Credit three hours. Prerequisite: 4561 or 7201 or equivalent. Not offered in 1971–72.
Collective oscillations in a cold plasma; waves in a warm plasma; application to natural phenomena. Nonlinear theory of collision-free shocks. Quantum effects in solid state plasma waves; plasma-phonon interactions. Introduction to radiation and scattering in plasmas. At the level of *Theory of Plasma Waves* by Stix; and *Radiation Processes in Plasmas* by Bekefi.]

7301 Fluid Mechanics (g). Credit three hours. Mr. Shen.
The continuum and the stress tensor. Vectors and tensors. Strain and rate-of-strain tensors. Constitutive equations. The ideal elastic continuum. Boundary conditions. Elastic waves. The Newtonian fluid, viscosity and bulk viscosity, Navier-Stokes equations. Poiseuille flow; Rayleigh and Stokes problems. The concept of the boundary layer. The ideal-fluid approximation. Kelvin and Helmholtz theorems. Vorticity. Irrotational flows. Turbulence.

7302 Aerodynamics (g). Spring. Credit three hours. Mr. Sears.
Laplace's equation. Source, sink, and doublet. Vortices. Biot-Savart theorem, the flow field of a vortex. Spherical and cylindrical harmonics. Methods of singularity distributions. Complex-variable methods. Wing theory. Acoustics. Compressible flows, subsonic and supersonic. Shock waves. Hypersonic flow. Rotational flows. Magnetohydrodynamics. Flow in the boundary layer, Prandtl theory. Heat transfer; separation.

7303 Compressible Fluid Flow (g). Either term, on demand. Credit three hours. Mr. Seebass.
Aerodynamics of compressible fluids. Brief review of linear theories. Improvements on linear theory. Theory of sonic boom. Role of entropy in supersonic flows. Shock wave interactions. Exact theories; method of characteristics for rotational reacting flows; conical flows. Transonic flow theory and similitude. Viscous effects in compressible flows. Other topics of current interest.

7304 Theory of Viscous Flows (g). Spring. Credit three hours. Prerequisite: 7301, 7302. Mr. Shen.
Exact solutions of the Navier-Stokes equations. The small Reynolds number approximation. The boundary layer theory and the techniques for its solution. Compressibility effects. Stability of laminar flows. Turbulence.

7305 Hypersonic Flow Theory (g). Either term, on demand. Credit three hours. Prerequisite: 7301, 7302. Mr. Seebass.
Hypersonic small disturbance theory and the related similitude; blast wave analogy; entropy layers. Newtonian theory and shock layer structure. Constant density solutions. The blunt body problem; numerical techniques. Viscous and real gas effects; ideal dissociating gas; viscous interactions; other real gas phenomena.

7306 Atmospheric Motions (g). Either term, on demand. Credit three hours. Prerequisite: 7301 or 8134 or consent of the instructor. Mr. Seebass.
A one-semester course at the graduate level for students with a background in fluid mechanics. Contents will vary depending on student interest, but the material will emphasize an understanding of atmospheric motions on either a global or local scale. Topics include: radiative heating, heat budget; dynamic equations and circulation theorems; waves in stratified fluids, lee waves, Rossby waves; stability of rotating and stratified flows; frontal development; condensation and precipitation, thunderstorms, hurricane formation; plumes and thermals; numerical weather prediction; atmospheric boundary layer, turbulence in stratified flows; air-ocean interface; general circulation of the atmosphere.

7307 Acoustics and Aerodynamic Noise (g). Either term. Credit three hours.
Basic acoustics. Hearing. Reflection and absorption, noise control. Geometrical acoustics in inhomogeneous moving media. Kirchhoff and Poisson formulas, diffraction, scattering. Radiation from surfaces. Flow-generated noise due to turbulence and unsteady flows. Applications to aircraft noise. Propagation of sound through turbulence.

7801 Research in Aerospace Engineering (g). Prerequisite: admission to the Graduate School of Aerospace Engineering and/or approval of the director.
Independent research in a field of aerospace science. Such research must be under the guidance of a member of the staff and must be of a scientific character.

7901 Aerospace Engineering Colloquium (g). Credit one hour.
Lectures by Cornell staff members, graduate students, and visiting scientists on topics of interest in aerospace science, especially in connection with new research.

7902 Seminar in Aerospace Engineering (g). Credit two hours. Prerequisite: approval of the director.
Study and discussion of topics of current research interest in aerospace engineering. Members of the seminar will prepare and deliver reports on these topics, based on published literature.

7903 Plasma Physics Colloquium (g). Fall and spring. Credit one hour.

Lectures by staff members, graduate students, and visiting scientists on topics of current interest in plasma research.

Agricultural Engineering

(For a complete description of the courses in agriculture, see the *Announcement of the College of Agriculture.)*

152 Introduction to Agricultural Engineering Measurements (u). Spring. Credit three hours. One lecture, two laboratories. Mr. Levine.
A study of the principles and methods of engineering measurements. Fundamentals of measurements, sources of errors, and measurement systems will be considered. Special attention will be given to methods of obtaining measurements that are required in the solution of agricultural engineering problems. A one-half term study of surveying measurements will be completed. An appropriate computing language and elementary statistics will be taught as an integrated part of the solution of agricultural engineering measurement problems.

153 Engineering Drawing (u). Fall. Credit three hours. Two lectures, one laboratory. Mr. Longhouse.
Designed to promote an understanding of the engineer's universal graphic language. The lectures will deal primarily with spatial relationships involving the problem-solving techniques of descriptive geometry. The laboratories will develop a working knowledge of drawing conventions, standard and advanced drafting techniques, and their application to machine, architectural, and pictorial drawing problems. Graphs and engineering graphics (nomography and graphical calculus) will also be included. Students will accomplish their work with drafting machines as well as the standard T-square and board. The first half hour of the laboratory will be utilized as an instruction-recitation period.

421 Introduction to Environmental Pollution (u,g). Spring. Credit three hours. Three lectures. Mr. Ludington.
A general course dealing with the impairment of the environment by the wastes of man. The causes and effects of air, water, and soil pollution will be discussed. Fundamental factors underlying waste production, abatement, treatment, and control will be included. A selected number of wastes from urban, rural, and industrial areas will be used to illustrate the factors.

450 Special Topics in Agricultural Engineering (u). Spring. Credit one hour. Open only to seniors. Mr. French.
Presentation and discussion of the opportunities, qualifications, and responsibilities for positions of service in the various fields of agricultural engineering.

[**461 Agricultural Machinery Design (u,g).** Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: kinematics and components of machines. Mr. Gunkel. Not offered in 1971–72.
The principles of design and development of agricultural machines to meet functional requirements. Emphasis is placed on analog and digital computer-aided analysis and design, stress analysis, selection of construction materials, and testing procedures involved in agricultural machine development. Engineering creativity and design related to agricultural production systems are also stressed.]

462 Agricultural Power (u,g). Fall. Credit three hours. Two lectures, one laboratory. Prerequisite: engineering mechanics (dynamics), or equivalent. Mr. Rehkugler.
Utilization of internal combustion engine and other forms of energy in agriculture. Basic theory analysis and testing of internal combustion engines for use in farm tractors and other agricultural power applications. Specific study of tractor transmissions, Nebraska Tractor Tests, and soil mechanics related to traction and vehicle mobility. Economics and human factors in power use and application will be considered.

[**463 Processing and Handling Systems for Agricultural Materials (u,g).** Spring. Credit four hours. Three lectures, one laboratory. Mr. Furry. Not offered in 1971–72.
Processes such as size reduction, separation, metering, and drying will be studied. Psychrometrics, fluid flow measurement, and an introduction to dimensional analysis and controls for agricultural applications are included. Problem solutions will employ both the analog and digital computers. It is preferred that the student know how to write programs to utilize the digital computer, prior to enrolling in the course.]

471 Soil and Water Engineering (u,g). Spring. Credit three hours. Three lectures, one laboratory every other week. Prerequisite: fluid mechanics and soils or concurrent registration. Mr. Black.
The application of engineering principles to the problems of soil and water control in agriculture. Includes design and construction of drainage systems and farm ponds; design and operation of sprinkler systems for irrigation.

481 Agricultural Structures (u,g). Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: structural engineering and thermodynamics. Mr. Scott.
Synthesis of complete farmstead production units, including structures, equipment, and management techniques. Integrated application of structural theory, thermodynamics, machine design, and methods engineering to satisfy biological and economic requirements.

491 Highway Engineering (u,g). (Same as Civil and Environmental Engineering 2432.) Fall. Offered upon sufficient demand. Credit three hours. Prerequisite: consent of instructor. Mr. Spencer.
Principally directed study and individual or team investigations with one 2½-hour class session per week. Emphasis is on secondary roads in study of: economic considerations in road system improvement; road improvement planning and programming; road location and geometric design; engineering soil characteristics and classification; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces.

501 Similitude Methodology (g). Spring. Credit three hours. Two lectures, one laboratory. Mr. Furry.
Similitude methodology, including the use of dimensional analysis to develop general equations to define physical phenomena; model theory; distorted models; and analogies; with an introduction to a variety of applications in engineering. Problem solutions will employ both analog and digital computers. It is preferred that the student know how to write programs to utilize the digital computer, prior to enrolling in the course.

502 Instrumentation (g). Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: permission of instructor. Mr. Scott.
Emphasis is on the application of instrumentation concepts and systems to physical and biological measurements. Characteristics of instruments, applica-

tion of operational amplifiers and transistors for signal conditioning and interfacing, shielding and grounding; transducers for measurement of force, pressure, displacement, velocity, acceleration, temperature, light, and flow; and data acquisition systems, including telemetry, are considered.

504 Biological Engineering Analysis (g). Fall. Credit four hours. Three lectures. Prerequisite: consent of instructor or Engineering 1151. Mr. Cooke.
Engineering problem-solving strategies and techniques will be explored. The student will solve several representative engineering problems which inherently involve biological properties. The mathematical modeling will emphasize problem formulation and interpretation of results. The student's knowledge of fundamental principles will be extensively utilized. Principles of feedback control theory will be applied to biological systems.

[505 **Solid Waste Management (u,g).** Spring. Credit three hours. Prerequisite: permission of instructor. Mr. Loehr. Not offered in 1971–72.
Study of municipal, industrial, and agricultural solid wastes. Emphasis on waste characteristics, method of treatment, and disposal, and interrelationship with air, water, and land environment. Discussion of economic and political aspects. Intended primarily for graduate students but open to qualified undergraduates.]

506 Industrial Waste Engineering (u,g). (Same as Chemical Engineering 5731 and Civil and Environmental Engineering 2531.) Spring. Credit three hours. Primarily a graduate course, but open to upperclassmen in Chemical, Agricultural, or Civil and Environmental Engineering, or in the College Program with a major from these fields. Messrs. Loehr, Behn, and Wiegandt.
This course is offered jointly with Chemical Engineering and Civil and Environmental Engineering as an integrated presentation. The first third of the course is concerned with legal aspects, assimilatory capacity of receiving waters, joint industrial-municipal collection of wastes, and sewerage service charges. The second part covers waste sampling and analysis, treatment processes, waste-reduction possibilities, water quality and quantity, water reuse and recovery, and costs. The final third of the course includes specific industrial operations and selected case studies of industrial waste treatment. A study, in depth, of a particular waste problem is required of all students.

551–552 Agricultural Engineering Project (g). Credit six hours. (Required for M.Eng. degree.) Staff.
Comprehensive design projects utilizing real engineering problems to present fundamentals of agricultural engineering design. Emphasis on formulation of alternate design proposals, including economics and nontechnical factors and complete design of the best alternative.

601 General Seminar (g). Fall and spring. Fall term required of all graduate students majoring in the Field. Spring term, optional.

602 Power and Machinery Seminar (g).

603 Soils and Water Engineering Seminar (g).

604 Agricultural Structures Seminar (g).

605 Agricultural Waste Management Seminar (g).

606 Biological Engineering Seminar (g).

Seminars 602, 603, 604, 606, spring, credit one hour. Seminar 605, either term, credit one hour.

Applied and Engineering Physics

8051 and 8052 Project (g). Fall and spring. Credit three hours.
Informal study under direction of a member of the University staff. The objective is to develop self-reliance and initiative, as well as to gain experience with methods of attack and with overall planning in the carrying out of a special problem related to the student's field of interest.

8090 Informal Study in Engineering Physics (u,g). Either term.
Laboratory or theoretical work in any branch of engineering physics under the direction of a member of the staff.

8117 Contemporary Topics in Applied Physics (u). Spring. Credit three hours. The course will consist of lecture periods combined with recitations and some experiments. Staff.
Selected examples of contemporary applications of modern physics will be studied. The objective is to develop a semiquantitative understanding of the underlying physical principles and phenomena and the intrinsic limits they place on applications. Discussion will also include the interplay between physics and other factors (technological, scientific and, when relevant, social and political) which set limits on application of modern physics and influence its development. For example, lasers of different types will be analyzed and their limitations discussed in terms of energy levels, lifetimes of states, and other concepts of atomic physics, plus the limitations on laser development imposed by materials properties. Nuclear energy utilization will be studied in terms of the physics of fission, fusion, and plasmas, along with the technological and social factors affecting development of nuclear energy sources. Selected solid state devices will serve to illustrate the concepts of band structure and electron transport. Applications of physics in other sciences such as astrophysics and biology may also be included.

8123 Statistical Thermodynamics (u). Fall. Credit three hours. Mr. Blakely.
Quantum statistical basis for equilibrium thermodynamics, canonical and grand canonical ensembles, and partition functions. Thermal cycles and laws of thermodynamics, concepts of temperature, entropy, free energy, etc. Differential thermodynamic relations. Quantum and classical ideal gases and para-magnetic systems, Fermi-Dirac, Bose-Einstein and Maxwell-Boltzmann statistics.

8124 Statistical Physics (u). Spring. Credit three hours. Mr. Webb.
Statistical physics of electromagnetic radiation, phonons, metals, and low temperatures. Imperfect gases, molecules, phase transitions, and chemical equilibrium. Rate processes, fluctuations, electrical noise, dissipative processes, and elementary kinetic theory, with an introduction to the master equation, and the Boltzmann transport equation.

8133 Mechanics of Particles and Solid Bodies (u). Fall. Credit three hours. Three lectures, one recitation. Mr. Sack.
Primarily for majors in engineering physics. 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.

[8134 **Mechanics of Continua (u).** Spring. Credit three hours. Three lectures, one recitation. Mr. Sack. Not offered in 1971–72.

Strain and stress tensors; coordinate transformation; generalized Hooke's law; anisotropic solids; problems in static elasticity; wave propagation; anelasticity; elements of fluid mechanics (Euler's, Bernoulli's, and Navier-Stokes's equations and applications to flow around bodies, boundary layer, turbulence).]

8155 Intermediate Electromagnetism (u). Fall. Credit three hours. Prerequisite: Physics 234, 236, and coregistration in Mathematics 421 or consent of the instructor. Mr. Kuckes.
Topics include vector calculus, electrostatic and magnetostatic fields as solutions of boundary value problems, dielectric and magnetic media, mechanical and electric energy and pressure. Also, electric induction phenomena, skin effect, and the introduction of displacement current. Emphasis on the application of concepts to physical phenomena and engineering. At the level of *Lectures on Physics*, Vol. II, by Feynman, and *Foundations of Electromagnetic Theory* by Reitz and Milford.

8156 Intermediate Electrodynamics (u). Spring. Credit three hours. Prerequisite: 8155, coregistration in Mathematics 422, or consent of the instructor. Mr. Kuckes.
Development of electromagnetic wave phenomena and radiation. Topics include transmission lines, waveguides, wave properties of a dispersive media. Also, radiation and scattering phenomena, reciprocity, physical optics, and special relativity. Emphasis is on concepts and their application to physical phenomena and engineering. At the level of *Lectures on Physics*, Vol. II, by Feynman, and *Classical Electromagnetic Radiation* by Marion.

8161 Introductory Quantum Mechanics (u). Spring. Credit four hours. Three lectures, one recitation. Prerequisite: 8133 or Physics 319, coregistration in Mathematics 422 and 8156 or Physics 326. Mr. Nelkin.
A first course in the systematic theory of quantum phenomena. Topics will include illustrative solutions of the Schroedinger equation, angular momentum, spin and the exclusion principle, perturbation theory, an introduction to symmetries, and the Dirac formulation. The course, whose content is similar to Physics 443, is made available in the spring semester to allow flexibility of scheduling. At the level of *Introduction to Quantum Theory* by Park, and Volume III of the Feynman *Lectures on Physics*.

8205 Electrical and Magnetic Properties of Engineering Materials (g). (Same as Materials Science and Engineering 6605.) Fall. Credit three hours. Prerequisite: Physics 454 or consent of instructor.
Electrical properties of semiconductors. Metallic alloys. Ferromagnetic materials. Superconductivity. Optical and dielectric properties of insulators and semiconductors. At the level of *Introduction to Solid State Physics* by Kittel, *Physics of Magnetism* by Chikazumi, *Superconductivity* by Lynton, *The Effect of Metallurgical Variables on Superconductivity Properties* by Livingston and Schadler.

8211 Principles of Diffraction (g). (Same as Materials Science and Engineering 6611.) Fall. Credit three hours. Mr. Batterman.
Production of neutrons, x rays, absorption, scattering, Compton effect. Diffraction from periodic lattices, crystal symmetry, single crystal and powder techniques. Fourier methods, thermal vibration and scattering, diffraction from liquids and gases, introduction to dynamical diffraction of x rays and electrons, extinction phenomena, and perfect crystals. Selected experiments in diffraction.

8212 Selected Topics in Diffraction (g). (Also Materials Science and Engineering 6612.) Spring. Credit three hours. Three lectures. Prerequisite: 8211, or consent of the instructor. Mr. Batterman.
Dynamical diffraction: Ewald-von Laue theory of dynamical diffraction applied to x rays and electrons. Currently developing theory and application to defects in solids. Phenomena investigated via diffuse scattering: phonons, measurement of dispersion curves, frequency spectrum, Debye temperatures, vibrational amplitudes. Order-disorder phenomena: short and long-range order, Guinier-Preston zones. Selected topics of current interest related to x ray, neutron, and electron diffraction, with contributions from other members of the faculty.

8252 Selected Topics in Physics of Engineering Materials (g). Fall. Credit one hour. Primarily for candidates for Master of Engineering (Engineering Physics); others with consent of instructor.
Seminar-type discussion of special topics in the field of engineering materials, such as plastic and rheological properties; dielectric and magnetic behavior; semiconductors; radiation damage, etc. Emphasis is given to the interpretation of the phenomena in light of modern theories in physics of solids and liquids and their impact on the engineering applications. Current literature is included in the assignments.

[**8261 Kinetic Equations (g).** (Same as Electrical Engineering 4661.) Spring. Credit three hours. Three lectures. Prerequisite: Physics 561, 562 or permission of instructor. Not offered in 1971–72.
Designed for students wishing a firm foundation in fluid dynamics, plasma-kinetic theory, and nonequilibrium statistical mechanics. Brief review of classic dynamics. The concept of the ensemble and the theory of the Liouville equation. Prigogine and Bogoliubov analysis of the BBKGY sequence. Chapman-Kolmogorov analysis of Markovian kinetic equations. Derivation of fluid dynamics. Kinetic formulation of the stress tensor. Boltzmann, Krook, Fokker-Planck, Landau, and Balescu-Lenard equations. Properties and theory of the Linear Boltzmann collision operator. Chapman-Enskog and Grad methods of solution of the Boltzmann equation. Klimontovich formulation. Coarse graining and ergodic theory. At the level of *Introduction to the Theory of Kinetic Equations* by Liboff.]

8262 Physics of Solid Surfaces (g). (Also Materials Science and Engineering 6762). Spring. Credit three hours. A lecture course for graduate students and upperclassmen. Messrs. Rhodin and Blakely.
An introductory critical review of advances in the theory of the solid state related directly to surface phenomena. Thermodynamics of surface phases, atomistic theory of surfaces, and dynamics of interaction of electrons, ions, and atoms with surfaces are considered. Reference is made to application of the theory to surface and interface phenomena in metals, insulators, and semiconductors as much as possible. Presented at the level of *Advances in Solid State Physics* by Seitz and Turnbull, eds.

8301 Nuclear Energy and the Environment (u). Fall. Credit three hours. Two lectures and one two-hour recitation or laboratory per week. The level of presentation assumes knowledge of introductory physics, chemistry, and calculus, but previous knowledge of biology is not required. Messrs. Kostroun, Cady, and Clark.
Fundamentals of nuclear radiations and their measurement and interaction with matter, the natural radiation environment, and sources of man-made radioactivity (five weeks); radiation chemistry, radiation biology, somatic and genetic effects of nuclear radiation, move-

ment of radioactive materials in the biosphere, and bases of radiation protection standards (five weeks); environmental effects of nuclear electricity generation and nuclear fuel mining, processing, and waste storage, control of radiation hazards, and waste heat problems (four weeks).

8303 Introduction to Nuclear Science and Engineering (u). Spring. Credit three hours. Prerequisite: sophomore physics and mathematics. Mr. Kostroun.
An introductory course in low-energy nuclear physics and nuclear engineering for juniors and seniors. The objective is to acquaint students with low-energy nuclear physics and some of its practical applications. The following topics will be covered: properties and structure of nuclei; radiations emitted by nuclei and their interaction with matter; nuclear reactions, with emphasis on fission and fusion processes; the neutron chain reaction; types and uses of nuclear reactors; practical applications of nuclear radiations, e.g., neutron activation analysis and radioactive tracer analysis.

8309 Low-Energy Nuclear Physics (g). Spring. (Fall term, beginning 1972–73). Credit four hours. Three lectures. Prerequisite: an introductory course in modern physics including quantum mechanics. Also open to qualified seniors. Mr. McPherson.
The nuclear interaction. Properties of ground and excited states of nuclei and models of nuclear structure; alpha, beta, gamma radioactivity and fission; low-energy nuclear reactions—resonant and nonresonant scattering and absorption. At the level of *Introduction to Nuclear Physics* by Enge.

8310 Nuclear Structure Physics (g). Spring. Credit three hours. Prerequisite: 8309 or Physics 444 or equivalent. Mr. Kostroun.
Topics include: symmetry properties of nuclei, the collective model, basic reaction theory, compound and direct reactions, the optical model, charged particle reactions. At the level of *Physics of the Nucleus* by Preston.

8312 Nuclear Reactor Theory I (g). Fall. Credit four hours. Three lectures. Prerequisite: one year of advanced calculus and an introductory course in nuclear physics. Also open to qualified seniors. Messrs. Cady and Clark.
The physical processes in the neutron chain reaction are described. The theory of neutron slowing down, moderation, and spatial diffusion are developed and applied to these processes. The theories of fast effect, resonance absorption, and thermal utilization are developed for homogeneous reactors. Nuclear reactor kinetics and neutron transport theory are introduced. At the level of *Nuclear Reactor Theory* by Lamarsh.

8313 Nuclear Reactor Theory II (g). Spring. Credit three hours. Three lectures. Prerequisite: 8312. Mr. Cady.
A continuation of 8312, primarily intended for students planning research in nuclear reactor physics and engineering. The Boltzmann linear transport equation, its adjoint, and their approximate solutions are developed and applied to the heterogeneous neutron chain reactor. The theories of fast fission effect, resonance escape, and thermal utilization are developed for heterogeneous reactors. The escape probability formulation of reactor lattices, the neutron importance function, perturbation theory, temperature coefficients of reactivity, and fission product poisoning are also treated. At the level of *The Physical Theory of Neutron Chain Reactors* by Weinberg and Wigner.

8333 Nuclear Reactor Engineering (g). Fall. Credit four hours. Prerequisite: introductory course in nuclear engineering. Also open to qualified seniors. Mr. Cady.
A selected set of topics representing the fundamentals of nuclear reactor engineering; energy conversion and power plant thermodynamics, reactor plant fluid flow and heat transfer, thermal stresses, radiation protection and shielding, routine and accidental discharge of radionuclides from nuclear reactors, and nuclear fuel cycles. At the level of *Nuclear Reactor Engineering* by Glasstone and Sesonske.

8334 Nuclear Engineering Design Seminar (g). Spring. Credit four hours. Prerequisite: 8333. Mr. Cady.
A group design study of a selected nuclear reactor system. Emphasis is on safety, siting, and radiation protection in the design of nuclear power systems.

8351 Nuclear Measurements Laboratory (g). Either term. Credit four hours. Two 2½-hour afternoon periods. Prerequisite: some knowledge of nuclear physics. Also open to qualified seniors. Mr. Clark.
Laboratory experiments plus lectures on interaction of radiation with matter and on radiation detection, including electronic circuits. Twenty different experiments are available in the fields of nuclear and reactor physics and radiation protection. Among these are experiments on emission and absorption of radiation, radiation detectors and nuclear electronic circuits, interactions of neutrons with matter (absorption, scattering, moderation, and diffusion), activation analysis and radiochemistry, and properties of a subcritical assembly. Many of the experiments use the TRIGA Reactor. The student is expected to perform eight to ten experiments, selected to meet his needs. Some stress is placed on independent work by the student.

8352 Advanced Nuclear and Reactor Laboratory (g). Either term. Credit three hours. Two 2½-hour afternoon periods. Prerequisite: 8351 and 8309 or 8312.
Laboratory experiments plus lectures on experimental methods in nuclear physics and reactor physics. Ten different experiments are available, among them ones using the Zero Power Reactor critical facility.

8501 Physics of Atomic and Molecular Processes (u,g). Spring. Credit three hours. Prerequisite: 8161, Physics 443, Chemistry 593, or consent of instructor. Mr. Fleischmann.
An introduction to the basics of contemporary problems in the physics of atomic and molecular processes, including atomic structure, chemical bonding, radiation resonance processes, and elastic and inelastic collisions. At the level of *Quantum Mechanics* by Blokhintsev, and the final chapters of *Introduction to Quantum Mechanics* by Park.

[**8503 Special Topics in Advanced Plasma Physics. (g).** Fall. Messrs. Auer and Rostoker. Not offered in 1971–72.
An advanced course which discusses in some detail research being pursued at Cornell. Topics will include high β plasmas and collision free shocks, plasma turbulence, and relativistic electron plasmas.]

8505 Topics in Statistical Physics (g). Fall. Credit three hours. Prerequisite: 8124 or Physics 562 or Chemistry 596. Coregistration in Physics 653 preferable. Offered for the first time in 1971, and subsequently upon sufficient demand. Mr. Nelkin.
Selected topics of current research interest in statistical physics. This year these will include: time correlation functions and collective motion in disordered systems, dynamical phenomena in the neighborhood of critical points, and statistical theory of turbulence. A

formalism using memory functions and projection operators, originated by Zwanzig and extended by Mori, will be systematically presented at the beginning of the course and applied to the first two topics.

[**8512 Electron Microscopy and Diffraction (g).** Spring. Credit three hours. Mr. Silcox. Not offered in 1971–72.
A discussion of selected topics in the areas of electron microscopy and diffraction, with the major emphasis on microscopy. Probable topics include: elastic and inelastic electron scattering from atoms, molecules, and aggregates of matter; nature of image formation—amplitude, phase, and diffraction contrast; resolution; magnetic domain structure as a phase grating and atomic planes as a diffraction grating; kinematical 2-beam, and n-beam dynamical theories of perfect crystals; phenomenological treatment of absorption; extension to imperfect crystals—diffraction contrast from defects such as dislocations, stacking faults, coherent and incoherent precipitates; discussion of inelastic scattering; instrumental and fundamental limitations on source properties and image formation capabilities and reasons for current research activities devoted to extending the capabilities.]

[**8601 Photosynthesis (u,g).** Fall. Credit three hours. Given in alternate years. Prerequisite: Chemistry 104 or 108, Mathematics 108 or 111, and Physics 102 or 108, or consent of instructor. Mr. Clayton. Not offered in 1971–72.
A detailed study of the process by which plants use light in order to grow, emphasizing physical and physico-chemical aspects of the problem.]

8603 General Photobiology (u,g). Fall. Credit three hours. Given in alternate years. Prerequisite: same as for course 8601. Lectures, M 1:25, T Th 10:10. Mr. Clayton.
An introduction to biological applications of optics, and a study of the major interactions between light and living matter as encountered in photosynthesis, vision, regulation of physiology and development, bioluminescence, and damage by ultraviolet and visible light.

8901 Issues and Methods in Applying Science (g). Fall. Credit three hours. For graduate students, and upperclass undergraduates with consent of the instructor. Mr. Webb.
This course is designed to offer graduate students majoring in the physical sciences, engineering, business, or social sciences an introduction to the issues, methods, and problems involved in the application of physical science in "mission-oriented" research, development, industrial technology, and engineering and in technological problems of contemporary society. Presentation is in seminar style, with visiting lecturers, discussion sessions, and case studies. A detailed syllabus may be obtained from Mr. Webb, 237 Clark Hall.

Chemical Engineering

5041 Nonresident Lectures (u). Fall. One lecture. Messrs. Bischoff and Winding.
Given by lecturers invited from industry and from selected departments of the University for the purpose of assisting students in their transition from college to industrial life.

[**5061 Seminar on the Engineer and Society (u,g).** Fall. Credit one hour. Not offered in 1971–72.
Review of major social changes caused by science and technology; discussion of current social challenges to the engineer, with particular emphasis on the chemical process industry.]

5101 Mass and Energy Balances (u). Fall and spring. Credit three hours. Three lectures, one computing session. Mr. Thorpe.
Engineering problems involving material and energy balances. Flow-sheet systems and balances. Total energy balances and flow systems.

[**5102 Equilibria and Staged Operations (u).** Fall. Credit three hours. Three lectures, one computing session. Mr. Thorpe. Not offered in 1971–72.
Phase equilibria and phase diagrams. The equilibrium stage; mathematical description of single and multistage operations; analytical and graphical solutions.]

5103 Chemical Engineering Thermodynamics (u). Fall and spring in 1971–72; thereafter, spring. Credit three hours. Three lectures. Prerequisite: Chemistry 287, 288. Mr. Von Berg.
A study of the first and second laws with application to batch and flow processes. Physical and thermodynamic properties; availability; free energy; chemical equilibrium. Applications to gas compression, refrigeration, power generation, adiabatic reactors, and chemical process development.

5105 Advanced Chemical Engineering Thermodynamics (g). Fall. Credit three hours. Three lectures. Prerequisite: 5103 or equivalent. Mr. Von Berg.
Application of the general thermodynamic methods to advanced problems in chemical engineering. Evaluation, estimation, and correlation of properties; chemical and phase equilibrium.

5106 Reaction Kinetics and Reactor Design (u,g). Spring. Credit three hours. Three lectures. Prerequisite: 5304.
A study of chemical reaction kinetics and principles of reactor design for chemical processes.

5107 Reactor Design (g). Fall. Credit three hours. Three lectures. Mr. Harriott.
Effects of heat transfer, diffusion, and non-ideal flow on reactor performance. Optimum design for complex reactions. Analysis of current literature on topics such as partial oxidation, catalytic cracking, hydrogenation, and polymerization.

[**5109 Advanced Chemical Kinetics (g).** Spring. Credit three hours. Three lectures. Prerequisite: 5106 or equivalent. Not offered in 1971–72.
Reaction rate theory and application to complex reaction mechanisms; adsorption phenomena and application to heterogeneous catalytic reactions with emphasis on current theoretical progress.]

5161 Phase Equilibria (g). Fall. Credit three hours. Three lectures. Prerequisite: physical chemistry. Mr. Thorpe.
A detailed study of the pressure-temperature-composition relations in binary and multi-component heterogeneous systems where several phases are of variable composition. Prediction of phase data.

[**5205 Chemical Process Seminar (g).** Fall. Credit two hours. Mr. Wiegandt. Not offered in 1971–72.
A discussion of recent advances in chemical process development.]

5257 Materials (u). Fall. Credit five hours. Three lectures, two laboratories. Mr. Cocks.
An introductory presentation of the nature, production, properties, applications, and behavior under service conditions of materials. Laboratory includes elements of chemical microscopy, crystallography, and the microscopic characterization of materials.

5304 Introduction to Rate Processes (u). Spring. Credit three hours. Three lectures, one computing session. Prerequisite: 5102. Mr. Scheele.
An introduction to fluid mechanics, heat and mass transfer.

[**5305 Analysis of Separation Processes (u).** Spring. Credit three hours. Three lectures, one computing session. Prerequisite: 5304, familiarity with CUPL, the Cornell computing language. Not offered in 1971–72.
Analysis of separation processes involving phase equilibria and rate of mass transfer; extensive use of the digital computer. Phase equilibria; binary, multicomponent, and extractive distillation; liquid-liquid extraction; gas absorption.]

5312 New Separation Techniques (u,g). Fall. Credit three hours. Three lectures. Mr. Finn.
Lectures, problems, and demonstrations of new or less common separation techniques such as chromatography; ion exchange, electrophoresis, and membrane operations; analysis, design, and scale-up.

5353 Unit Operations Laboratory (u). Fall. Credit three hours. Two lectures, one laboratory. Prerequisite: 5304. Messrs. Bischoff, Harriott, Wiegandt, and Winding.
Laboratory experiments in fluid dynamics, heat transfer, and mass transfer. Correlation and interpretation of data. Technical report writing.

5354 Project Laboratory (u). Fall and spring. Credit three hours. Prerequisite: 5353. Staff.
Special laboratory projects involving bench-scale or pilot-plant equipment.

5501 Methods of Chemical Engineering Analysis (g). Fall. Credit three hours. May be taken by undergraduates with the permission of the instructor. Mr. Bischoff.
Methods of mathematical analysis of direct applicability in thermodynamics, transport phenomena, and chemical reactor design.

5505, 5506 Advanced Transport Phenomena (g). Fall and spring. Credit four hours. Messrs. Harriott and Scheele.
An integrated treatment of momentum, mass and heat transfer. Molecular transport; the equations of change; viscous laminar flow of Newtonian and non-Newtonian fluids; perfect fluid theory; boundary layer theory; unsteady-state transfer; penetration theory; models of mass and heat transfer; flow stability; turbulent transport; simultaneous heat and mass transfer; applications to industrial operations.

5508 Diffusion in Membranes and Porous Solids (g). Spring. Credit two hours. Mr. Harriott.
Theories for diffusion of gases and liquids in porous solids, porous membranes, and dense membranes. Problems in analysis and correlation of experimental results.

[**5510 Numerical Methods in Chemical Engineering I (g).** Fall. Credit three hours. Two lectures, one computing. Not offered in 1971–72.
Application of computer methods to solution of complex chemical engineering problems. Emphasis on applications of numerical analysis and optimization of nonlinear systems.]

5512 Numerical Methods in Chemical Engineering II (g). Spring. Credit three hours. Two lectures, one computing.
Application of computer methods to solution of complex chemical engineering problems. Linear programming and simulation and design of chemical processes.

5605, 5606, 5607, 5608 Design Project (g). Fall and spring. Credit variable.
Individual projects involving the design of chemical processes and plants. Estimation of costs of construction and operation; variation of costs and profits with rate of production.

[**5609 Mixing and Mechanical Separations (g).** Fall. Credit three hours. Three lectures. Prerequisite: 5304 or consent of instructor. Mr. Smith. Not offered in 1971–72.
Principles of mixing of gases, liquids, and solids; agitation; solid suspension; gas dispersion and chemical reaction; filtration; sedimentation; special mechanical separations.]

5621 Process Design and Economics (g). Fall. Credit six hours. Prerequisite: 5103, 5304, 5305. Mr. York.
Methods for estimating capital and operating costs. Performance, selection, design, and cost of process equipment. Process development and design. Market research and survey.

5622 Process and Plant Design (g). Spring. Credit six hours. Prerequisite: 5621. Continuation of 5621. Staff.
Process design, including reactors, process equipment, and separating systems. Layout and model of process units. Plant location, design, and layout. Cost estimates and project evaluation.

[**5623 Chemical Process Evaluation (u).** Fall. Credit four hours. Not offered in 1971–72.
A study of the important chemical processes.]

5624 Chemical Process Synthesis (u). Spring. Credit four hours. Mr. Wiegandt.
A consideration of process and economic alternatives in selected chemical processes, along with technological assessment.

5635 Marketing of Chemical Products (g). Spring. Credit three hours. Three lectures. Prerequisite: 5621. Mr. Hedrick.
Examination of marketing activities, organizations, and costs in the distribution of chemicals. Chemical prices. A market research project is required.

5636 Economics of the Chemical Enterprise (g). Fall. Credit three hours. Three lectures. Prerequisite: 5621. Mr. Hedrick.
Research economics; feasibility studies; information sources; venture analysis; planning.

[**5641 Inventions, Patents, and Trade Secrets (g).** Fall. Credit three hours. Prerequisite or parallel: 5621. Not offered in 1971–72.
Protection of inventions and trade secrets. Statutory and other legal requirements for patentability of inventions. Evaluation of patents. Role and management of patents in planning growth and expansion into new product lines.]

[**5642 Development Economics (g).** Spring. Credit three hours. Prerequisite: 5621, 5622, 5641. Not offered in 1971–72.
Planning, evaluation, and management of development activities in the process industries as related to research, processing, new products, markets, and long-range growth.]

5717 Process Control (g). Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: 5304. Mr. Edwards.
Dynamic response of processes and control instruments. Use of frequency response analysis. Laplace transforms and electronic analogs to predict the behavior of feedback control systems.

5731 Industrial Waste Engineering (u,g). (Same as Agricultural Engineering 506 and Civil and Environmental Engineering 2531.) Spring. Credit three hours. Primarily a graduate course, but open to upperclassmen in Chemical, Agricultural, or Civil and Environmental Engineering, or in the College Program with a major from these fields. Messrs. Loehr, Behn, and Wiegandt.
This course is offered jointly with Agricultural Engineering and Civil and Environmental Engineering as an integrated presentation. The first third of the course is concerned with legal aspects, assimilatory capacity of receiving waters, joint industrial-municipal collection of wastes, and sewerage service charges. The second part covers waste sampling and analysis, treatment processes, waste-reduction possibilities, water quality and quantity, water reuse and recovery, and costs. The final third of the course includes discussions of specific industrial operations and selected case studies of industrial waste treatment. A study, in depth, of a particular waste problem is required of all students.

5741 Petroleum Refining (g). Fall. Credit three hours. Three lectures. Prerequisite: 5304. Mr. Wiegandt.
A critical analysis of the processes employed in petroleum refining.

5742 Polymeric Materials (u,g). Fall. Credit three hours. Three lectures. Mr. Winding.
Chemistry and physics of the formation and characterization of polymers. The engineering applications of polymers as plastics, fibers, rubbers, and coatings.

5743 Properties of Polymeric Materials (g). Spring. Credit three hours. Three lectures. Prerequisite: 5742. Mr. Rodriguez.
Phenomenological aspects and molecular theories of non-Newtonian flow, viscoelasticity, and ultimate tensile properties. Special topics.

5746 Case Studies in the Commercial Development of Chemical Products (g). Spring. Credit three hours. Three lectures. Prerequisite or parallel: 5622. Mr. Hedrick.
Detailed analysis of specific cases involving the development of new chemical products. Particular emphasis is given to planning activities, research justification, and market forecasting. Profitability calculations and projections are required.

5748 Fermentation Engineering (u,g). Spring. Credit three hours. Two lectures, one recitation. Prerequisites or parallel: Chemistry 288 and any course in microbiology. Mr. Finn.
An advanced discussion of fermentation as a unit process. Topics include sterilization, aeration, agitation, and continuous fermentation.

5749 Industrial Microorganisms (g). Fall. Credit two hours. Prerequisite: organic chemistry and physical chemistry. Mr. Finn.
A brief introductory course in microbiology for students with a good background in chemistry.

5752 Polymeric Materials Laboratory (g). Spring. Credit two or three hours. One or two laboratories. Prerequisite: 5742. Mr. Rodriguez.
Experiments in the formation, characterization, fabrication, and testing of polymers.

5760 Nuclear and Reactor Engineering (g). Spring. Credit two hours. Two lectures. Prerequisite: consent of instructor. Mr. Von Berg.
Fuel processing and isotope damage; biological effects and hazards; shielding; radiation chemistry.

5761 Topics in Bioengineering (g). Spring. Credit two hours. Two lectures. Prerequisite: 5748 or consent of instructor. Mr. Edwards.
Analysis of transport phenomena, reaction kinetics, process dynamics and control, and optimization in biological systems. Topics include the dynamics of cell and virus population growth and facilitated transport in membranes.

5770 Engineering Analysis of Physiological Systems (u,g). Spring. Credit three hours. Mr. Bischoff.
Engineering analysis and mathematical description of flow, transport phenomena, and chemical reactions involved in physiological system function. Cell and body fluid properties, the circulatory system and blood flow, renal system models, transport of drugs and other solutes, artificial organ design.

5790 Consumer Products Engineering (u,g). (Same as Industrial Engineering and Operations Research 9114.) Fall. Credit three hours. Two lectures, one computing session. Open to qualified seniors and graduate students in engineering. Mr. Hedrick.
The organization and the interrelated departmental functions for the development of new consumer products. Case studies are drawn from industry to describe the special problems and situations encountered. The role of scientists and engineers in the consumer product industries is stressed.

[**5851 Chemical Microscopy (u,g).** Spring. Credit three hours. One lecture, two laboratories. Prerequisite or parallel: physical chemistry (e.g., Chemistry 287, 288, or 389, 390) and Physics 233, 234, or special permission. Not offered in 1971–72.
Microscopical examination of chemical and technical materials, processes, and products. The optics of the microscope, measurements, particle size determination, analyses of mixtures, optical crystallography, crystallization, phase changes, and colloidal phenomena.]

[**5857 Electron Microscopy (g).** Spring. Credit three hours. One lecture, two laboratories. Prerequisite: 5851 or special permission. Mr. Cocks. Not offered in 1971–72.
An introductory course in electron microscopy. The optics of the microscope, the operation and care of the microscope, methods of specimen preparation, and the interpretation of microscopical images.]

5859 Advanced Chemical Microscopy (g). Offered on demand either term. Credit variable. Prerequisite: 5851 and special permission. Mr. Cocks.
Laboratory practice in special methods and special applications of chemical microscopy.

5900 Seminar (g). Fall and spring. Credit one hour. General chemical engineering seminar required of all graduate students majoring in the field of chemical engineering.

5903 Seminar in Biochemical Engineering (g). Spring. Credit one hour.
Advanced topics in the engineering applications of biophysics and biochemistry. Discussion of current research in the field.

5909 Research Seminar (g). Fall. One lecture. Required of all students enrolled in the predoctoral honors program.
An introduction to the research methods and techniques of chemical engineering.

5952, 5953, 5954 Research Project (g). Fall and spring. Credit three hours; additional credit by special permission. Prerequisite: 5304.

Research on an original problem in chemical engineering.

5955, 5956 Special Projects in Chemical Engineering (g). Either term. Credit variable.
Research or studies on special problems in chemical engineering.

Civil and Environmental Engineering

2001 Thesis (g). The thesis gives the student an opportunity to work out a special problem or make an engineering investigation, to record the results of his work, and to obtain academic credit for such work. Registration for the thesis must be approved by the professor in charge at the beginning of the semester during which the work is to be done. Individual courses may be arranged to suit the requirements of graduate students. They are intended to be pursued under the immediate direction of the professor in charge, the student usually being free from the restriction of the classroom and working either independently or in conjunction with others taking the same course.

2002 Civil and Environmental Engineering Practice (u,g). On demand. Credit three hours. Prerequisite: fourth year or graduate standing. Staff.
Analysis of large engineering works; planning and organizing engineering and construction projects; professional practice; feasibility evaluations; financial justification of projects; social and political implications. The case method is used extensively.

2010 Civil and Environmental Engineering Design Project I (g). Fall. Credit two hours. Normally required for students in the M.Eng. (Civil) program. Staff.
Design of a major civil engineering project embodying several aspects of civil engineering. First term of a two-term sequence. Planning and part of preliminary design to be accomplished in the fall term; remainder of preliminary design and final design in the spring term. Projects to be carried out by students working under the direction of a faculty project coordinator.

2011 Civil and Environmental Engineering Design Project II (g). Spring. Credit three hours. Prerequisite: 2010. Normally required for students in the M.Eng. (Civil) program. Continuation of 2010. Staff.

2301 Fluid Mechanics (u). Fall. Credit three hours. Three lecture-recitations. Mr. Brutsaert.
Fluid properties, hydrostatics, the basic equations of fluid flow, potential flow, dimensional analysis, flow in conduits, open channel flow.

2302 Hydraulic Engineering (u). Spring. Credit three hours. Two recitations, one laboratory. Prerequisite: 2301. Mr. Liggett.
Free surface and pipe flow, fluid meters and measuring devices, hydraulic machinery, unsteady flow, waste heat discharges into lakes and rivers, applications of fluid mechanics. The laboratory will include a number of experiments in fluid mechanics and hydraulic engineering.

2309 Hydrology (u,g). Spring. Credit two hours. Intended for nonengineering majors. Prerequisite: permission of instructor. Mr. 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.

2312 Experimental and Numerical Methods in Fluid Mechanics (u,g). Offered on demand. Credit two hours. Prerequisite: 2302 or permission of instructor. Staff.
Primarily a laboratory course for undergraduates and graduates; may be repeated for credit upon permission of the instructor. Emphasis is on planning and conducting laboratory and field experiments on numerical computation.

2315 Advanced Fluid Mechanics I (g). Fall. Credit three hours. Three recitations. Prerequisite, 2301. Mr. Liggett.
Introduction to vector and tensor notation. The equations of conservation of mass, momentum, and energy from a rigorous point of view. Similitude and modeling potential flow including circulation, vorticity, conformal mapping, and hodograph methods.

2316 Advanced Fluid Mechanics II (g). Spring. Credit three hours. Three recitations. Prerequisite: 2315. Mr. Liggett.
Exact solutions to the Navier-Stokes equations, the laminar and turbulent boundary layers, turbulence, introduction to non-Newtonian flow, and other topics.

[**2317 Free-Surface Flow (u,g).** Spring. Credit three hours. Three recitations. Prerequisite: 2315 or 2318, or permission of instructor. Mr. Liggett. Not offered 1971–72.
The formulation of the free-surface equations and boundary conditions. Shallow water theory and the theory of characteristics. Unsteady and two-dimensional flow in open channels.]

2318 Dynamic Oceanography (u,g). Fall. Credit three hours. Prerequisite: elementary fluid mechanics. Mr. Liggett.
The statics and dynamics of oceans and lakes. Currents in homogeneous and stratified bodies of water. Tides, seiches, waves, and tsunamis. Turbulence and diffusion.

2320 Analytical Hydrology (u,g). Fall. Credit three hours. Prerequisite: 2301 or its equivalent. Mr. 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.

2321 Flow in Porous Media (g). Spring. Credit three hours. Prerequisite: 2301 (also recommended, 2315). Mr. Brutsaert.
Fluid mechanics of flow through porous solids. The general equations of single phase and multiphase flow and the methods of solving the differential form of these equations. Hydraulics of wells, infiltration, ground water recharge, and other steady state and transient seepage problems in fully and partially saturated materials.

2391 Project (u,g). Offered on demand. Hours and credit variable. 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.

2392 Research in Hydraulics (g). Offered on demand. Hours and credit variable. Staff.
The student may select an area of investigation in fluid mechanics, hydraulic engineering, or hydrology. The work may be either of an experimental or theoretical nature. Results should be submitted to the instructor in charge in the form of a research report.

2393 Hydraulics Seminar (u,g). Spring. Credit one hour. 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.

2394 Special Topics in Hydraulics (u,g). On demand. Hours and credit variable. Staff.
Special topics in fluid mechanics, hydraulic engineering, or hydrology.

2401 Elements of Soil Mechanics (u). Spring. Credit three hours. Two lectures, one laboratory. Mr. Sangrey.
Soil properties; chemical nature; particle size distribution; Atterberg limits; permeability; principle of effective stress; compressibility; shear strength; the consolidation process. Introduction to bearing capacity; earth pressure; slope stability; settlement; seepage and the solution of practical problems. Laboratory tests for the measurement of soil properties.

2406 Engineering of Foundations and Earth Retaining Structures (u,g.) Fall. Credit three hours. Two lectures, one two hour period. Prerequisite: 2401. Mr. Sangrey.
Mechanics and development of earth pressure in relation to soil properties and deformation. Design of retaining walls and bulkheads. Principles of bearing capacity, stress and distribution, and settlement. Design of shallow and deep foundations, footing, raft, caisson, and pile foundations. Problems of construction and stability of excavations. Influence of groundwater flow on walls, foundations, and excavations.

2410 Engineering Properties of Soils (u,g). Fall. Credit three hours. Three lectures. Prerequisite, 2401. Mr. Sangrey.
Natural environments in which soils are formed; the chemical and physical nature of soils. Principle of effective stress; shear strength and compressibility of natural geotechnical materials. Sensitivity, partial saturation, organic and frozen materials, anisotropy. Primary and secondary consolidation. Soil properties influencing permeability.

2412 Graduate Soil Mechanics Laboratory (g). Spring. Credit three hours. Prerequisite: 2410. Mr. Sangrey.
Laboratory measurement of soil properties: classification tests; direct shear tests; triaxial tests for the measurement of pore water pressure; strength parameters. Pore pressure dissipation tests. Relationship of laboratory tests to field behavior.

2414 Advanced Geotechnical Engineering (g). Fall. Credit three hours. Three lectures. Prerequisite: 2406 or equivalent. Mr. Sangrey.
A review in more intensive detail of topics covered in 2406, with additional discussion of recent improvements. Topics include site investigations; theories of bearing capacity for shallow and deep foundations; earth pressure on retaining walls, braced excavations, sheet pile walls, and tunnels; settlement and consolidation.

2416 Slope Stability: Earth and Rockfill Dams (u,g). Spring. Credit three hours. Two lectures and one two-hour period. Prerequisite: 2401. Mr. Sangrey.
Principles of stability for earth and rock slopes; effects of pore water pressure; short and long term stability; problems of drawdown; analysis of landslides and dam stability; principles of earth and rockfill dam design; internal pore water pressures and drainage; filters; relief wells; foundation problems; grouting; cut-offs; control and instrumentation.

2418 Case Studies in Soil Mechanics and Foundation Engineering (g). Spring. Credit three hours. Staff.
Study of real engineering problems of various types; importance of the geological environment in recognizing the nature of field problems; application of mechanics and soil properties to obtain engineering solutions. Preparation of engineering reports.

2431 Pavement Design and Construction (u,g). On demand. Credit three hours. Two lectures, one laboratory. Prerequisite: 2401 or permission of the instructor. Mr. Hewitt.
Part I: subgrade evaluation; compaction; drainage and frost action; stabilization. Part II: aggregates; bituminous materials; evaluation of flexible pavement components; design and construction of flexible pavement structure. Part III: design and construction of rigid pavements.

2432 Highway Engineering (u.g). (Same as Agricultural Engineering 491.) Fall. Offered upon sufficient demand. Credit three hours. Prerequisite: consent of instructor. Mr. Spencer.
Principally directed study and individual or team investigations with one 2½-hour class session per week to be arranged. Emphasis is on secondary roads and study of the following: economic considerations in road system improvement; road improvement planning and programming; road location and geometric design; engineering soil characteristics and classification; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces.

2445 Field Practice in Geotechnical Engineering (u,g). Fall and spring. Credit one hour each term. Field studies are conducted as two-day trips allocated to appropriate weekends in each term. (The student is expected to pay transportation and related costs, amounting to approximately $85.) Prerequisite: 2401 or permission of instructor. Staff.
This course is designed to provide experience with field conditions in important project environments within reach of the campus, including construction scenes in New York and central Pennsylvania. Reports on various sites are required. The program includes field testing and sampling; resistivity and seismic probing of soils and bedrock; soil moisture and density measurements using nuclear equipment. Engineering construction practices and site evaluation related to landslides, bedrock, drainage, and unstable soils. The influence of rock types, ground water, and soil materials on existing structures; appropriate design procedures applied to sophisticated structures at difficult sites.

2452 Elements of Surveying (u). Fall. Credit two hours. One lecture, one laboratory. Mr. Lyon.
Fundamentals of engineering measurements. Study of observations and errors. Principles of recording data. Use of steel tape, level, and transit. Photogrammetry. Problems of particular interest to students in fields other than civil engineering.

2453 Principles of Navigation (u). Fall. Credit four hours. Three lectures, discussion period, and project work. Mr. Lyon.
Coordinate systems, chart projections, navigational aids, instruments, compass observations, tides and currents, sounding. Celestial navigation: time, spherical trigonometry, motion of the stars and sun, star identification, position fixing, use of Nautical Almanac. Electronic navigation.

2462 Geophysical Geodesy (u,g). Spring. Credit three hours. Three lectures. Mr. McNair.
Basic potential theory, Laplace and Poisson equa-

tions; gravity and potential field in, on, and outside the spheroid; figure of the earth, application of Stokes formula for determining undulations of the geoid and deflection of the vertical; applications of spherical harmonics.

2464 Geodetic Measurements (u,g). Spring. Credit three hours. Three lectures and occasional night observation periods. Prerequisite: 2451 or equivalent. Mr. Lyon.
Study of instrument systems and their applications in geodetic and related measurements, with emphasis on high quality results. Topics include: systems for leveling, angle measurement, electro-optical and other distance measurement systems, and astronomic determination of azimuth and geographical positions.

2466 Map Projections and Cartography (u,g). On demand. Credit three hours. Three lectures. Mr. Lyon.
Theory of map projections including conformal, equal-area, azimuthal equidistant *et al.* projections; coordinate transformations; plane coordinate systems for surveying. Design of map projections. Cartographic principles, systems, and related economic factors.

2473 Analytic Aerotriangulation (u,g). Credit three hours. Three lectures. Prerequisite: 2471. Mr. McNair.
Analysis, theories, and computation of stereostrip triangulation by direction cosines, vector, and matrix methods. Coplanarity and colinearity equations for relative orientation and absolute orientation. Stereogram assemblage and coordinate transformation of strip and block coordinates. Cantilever extension and general bridging solutions. Propagation of errors.

2480 Engineering Measurements and Evaluation of the Physical Environment (u). Fall (may be offered in spring if the demand is sufficient). Credit three hours. Two lectures, one laboratory. Intended for juniors as an introductory course. Staff.
Fundamentals of engineering measurements, including an introduction to surveying and photogrammetry and other methods of location of natural resources and cultural features, and an introduction to shallow subsurface exploration. Airphotos and other remote sensors, imagery acquisition, measurement, and interpretation. Evaluation of physical environment for engineering projects. Case studies are used to illustrate principles.

2481 Identification, Classification, and Measurements of Environmental Components (u,g). Spring (may be offered in fall if the demand is sufficient). Credit three hours. Two lectures, one laboratory. Prerequisite: 2480 or permission of the instructor. Staff.
Subjects include airphotos and other sensors used to identify surficial land uses and cultural features, including both rural and urban scenes; fundamentals of agricultural soils and their conversion to planning uses; topographic, hydrologic, soil, geologic, climatic, and thematic maps and an analysis of various land classification systems. Extension of principles and concepts of topographic and nontopographic photogrammetry. Measurement and significance of results displayed by photogrammetric and other remote sensing instruments. Ground control and sensor calibration. Introduction to systems of display of data. Ortho-photographs, inventory surveys, space photogrammetry, automatic mapping devices, image enhancement.

2482 Evaluation of Earth Resources I (u,g). Credit three hours. Two lectures, one laboratory. Prerequisite: 2481. Messrs. Belcher and Liang.
This course evaluates the interplay between the physical environment and major types of engineering projects. Earth resources are explored and evaluated in terms of their effect on engineering and planning decisions. Methods include field reconnaissance; engineering data, subsurface records and interpretation of *in situ* soils, soil maps, geologic maps, airphotos, and meteorological data.

2484 Analyses and Interpretation of Aerial Photographs (u,g). Fall (may be offered in spring if the demand is sufficient). Credit three hours. Two lectures, one laboratory. Prerequisite: 2481. Preregistration required. The student is expected to pay the cost of field trips and aerial photographs for use in a term project, amounting to approximately $15. Messrs. Belcher and Liang.
Methods of identification of a broad spectrum of soils, rocks, and drainage conditions. The significance of vegetative patterns of the world. Specific fields of application, such as in site evaluation for housing and industry, are emphasized.

2485 Advanced Interpretation of Airphotos and Imagery Patterns (g). Credit three hours. Two lectures, one laboratory. Prerequisite: 2484. Messrs. Belcher and Liang.
A study of physical environment by use of airphotos and other remote-sensing methods. Intensive practice using conventional photography. Projects using sequential photography, multiple spectral photography, space photography, and infrared thermal and radar imageries are included. The course includes lectures and team projects in laboratory and field. Available facilities include material for projects in city and regional planning, recreation, soil mapping, geologic mapping, conservation, ground and surface water, and civil engineering.

2486 Geophysical Measurements I (u,g). Credit three hours. Three lectures. Prerequisite: 2481, 9170, and college level physics. Messrs. Lyon and McNair.
Introduction to measurements of geophysical processes and their effect on environment, including earthquake mechanisms; introductory seismology with emphasis upon shallow seismic exploration of the earth's crust; and geopotential fields—gravity, electrical, and magnetic—and measurement of field anomalies. Geometric measurements related to these processes; quantitative evaluation of measurements; and use of evaluation methods for the design of systems and observing programs.

2487 Evaluation of Earth Resources II (g.) Credit three hours. Prerequisite: 2482. Messrs. Belcher and Liang.
Land use and resource inventory methods and resource reserves estimates. Restoration and rehabilitation of the environment, especially as related to areas of engineering responsibility. Special consideration is given to the unique qualities of tropical, arctic, and arid regions. Extensive resource materials are available for case studies.

2488 Geophysical Measurements II (u,g). Credit three hours. Two lectures and one laboratory. Prerequisite: 2486. Messrs. Lyon and McNair.
Extension of principles and concepts of photogrammetry to include stereoplotters, computational photogrammetry, and the related effects of curvature of the earth. Geometrical geodesy and related topics.

2491 Design Project in Geotechnical Engineering (u,g). On demand. Credit one to six hours. Staff.
Design problems frequently associated with the Master of Engineering program.

2492 Research in Geotechnical Engineering (g). On demand. Credit one to six hours. Staff.

For students who wish to study one particular area of geotechnical engineering in depth. The work may take the form of a laboratory investigation, field study, theoretical analysis, or the development of design procedures.

2493 Seminar in Geotechnical Engineering (u,g). On demand. Credit one to two hours. Staff.
Presentation and discussion of technical papers and current research in the general field of geotechnical engineering or one of its specialized fields.

2494 Special Topics in Geotechnical Engineering (u,g). On demand. Credit one to six hours. Staff.
Supervised study in small groups in one or more special topics not covered in the regular courses. Special topics may be of a theoretical or applied nature.

2495 Seminar in Geodetic and Photogrammetric Engineering (u,g). Fall and spring. Credit one hour. Mr. McNair.
Student presentation, discussion, and editing of technical papers and review of current research in geodesy, photogrammetry, cartography, and land surveying. Occasional guest speakers.

2501 Environmental Quality Engineering (u). Spring. Credit three hours. Three lecture-recitations. Prerequisite: upperclass standing in College of Engineering, or permission of the instructor. Messrs. Lawrence and Loucks.
Concepts of environmental quality, including ecological, resource, socioeconomic, and political-administrative considerations. Objectives and methods of environmental quality control, with emphasis on air, water, land, noise, and radioactivity. Introduction to natural phenomena, technology, and analytical skills pertinent to environmental quality control.

2502 Water Quality Engineering (u,g). Fall. Credit four hours. Three lectures, one laboratory or computing session. Prerequisite: 2301, 2501, or equivalent, or permission of instructor. Mr. Behn.
Introduction to water quality engineering, including water supply, and water and wastewater treatment and disposal. Principles applicable to the behavior of municipal and industrial effluents in natural waters. Elements of analysis and design of municipal water supply systems and wastewater and storm water collection and disposal systems.

2510 Chemistry of Water and Wastewater (u,g). Fall. Credit three hours. Three lecture-recitations. Prerequisite: one year of college chemistry and permission of the instructor. Mr. Lawrence.
Principles of physical, organic, inorganic, and biochemistry applicable to the understanding, design, and control of water and wastewater treatment processes and to reactions in receiving waters.

2513 Biological Phenomena and Processes (u,g). Fall. Credit four hours. Three lectures, one laboratory. Prerequisite: 2503 or equivalent and concurrent registration in 2510. Mr. Behn.
Theoretical and engineering aspects of biological phenomena and processes applicable to the removal of impurities from water, wastewater, and industrial wastes, and to their stabilization in receiving waters. Pertinent microbiological principles, biological oxidation kinetics, and eutrophication. Analysis and design of biological treatment processes. Laboratory studies of pertinent phenomena and processes.

2514 Chemical and Physical Phenomena and Processes (u,g). Spring. Credit four hours. Three lectures, one laboratory. Prerequisite: 2510 and 2513. Mr. Lawrence.
Theoretical and engineering aspects of chemical and physical phenomena and processes applicable to the removal of impurities from water, wastewater, industrial wastes, and receiving waters; reaction kinetics, transfer and dispersion phenomena, and fine particle mechanics. Analysis and design of conventional and advanced treatment and disposal processes. Laboratory studies of pertinent phenomena and processes.

2515 Water Resources Problems and Policies (u,g). Fall. Credit three hours. Lecture-discussion. Prerequisite: permission of the instructor. Intended primarily for graduate engineering and nonengineering students but open to qualified undergraduates. Mr. Dworsky.
A comprehensive approach to water resources planning and development. Historical and contemporary perspectives of water problems, organization, and policies.

2518 Water Resource Systems (g). Spring. Credit three hours. Prerequisite: 301, 2617, or 9522 or permission of instructor. Mr. Loucks.
Application of economics, engineering, and systems theory to water, wastewater, and related resource planning and management problems. Development of deterministic and stochastic models. Review of current literature.

2520 Environmental Quality Control (u,g). Spring. Credit three hours. Three lecture-discussions. Prerequisite: permission of instructor. Intended primarily for graduate students and seniors in engineering. Mr. Gates.
Environmental quality and pollution problems. Environmental quality control concepts, objectives, and methods; ecologic, economic, health, regulatory, and technologic considerations. Air and water quality criteria, standards, and control; disposal of solid wastes and radioactive wastes.

2530 Solid-Waste Management (u,g). Spring. Credit three hours. Three lectures, reports. Prerequisite: permission of the instructor.
Study of municipal, industrial, and agricultural solid waste. Emphasis on waste characteristics, methods of treatment and disposal, interrelationships with air, water, and land environment.

2531 Industrial Waste Engineering (u,g). (Same as Agricultural Engineering 506 and Chemical Engineering 5731.) Spring. Credit three hours. Primarily a graduate course, but open to upperclassmen in Civil and Environmental, Agricultural, or Chemical Engineering, or in the College Program with a major from these fields. Messrs. Loehr, Behn, and Wiegandt.
This course is offered jointly with Agricultural Engineering and Chemical Engineering as an integrated presentation. The first third of the course is concerned with legal aspects, assimilatory capacity of receiving waters, joint industrial-municipal collection of wastes, and sewerage service charges. The second part covers waste sampling and analysis, treatment processes, waste-reduction possibilities, water quality and quantity, water reuse and recovery, and costs. The final third of the course includes specific industrial operations and selected case studies of industrial waste treatment. A study, in depth, of a particular waste problem is required of all students.

2533 Environmental Quality (u,g). Fall and spring, on demand. Credit three hours. Three lecture-discussions; field trips. Prerequisite: permission of the instructor. Mr. Gates.
Introduction to environmental quality and pollution problems, and consideration of their relationship to

man. The ecologic, economic, regulatory, and technologic aspects of air quality control and water quality control. Waste treatment and disposal methods.

2534 Air Quality Control (u,g). Spring. Credit three hours. Three lecture-discussions. Prerequisite: permission of the instructor. Intended primarily for graduate students and seniors in engineering. Mr. Gates.
Elements of air quality control. Sources, nature, and interactions of gaseous and particulate pollutants in the atmosphere. Air quality criteria, standards, and legislation. Air quality control methods and technology.

2545 Water Resources Planning Seminar (u,g). Spring. Credit three hours. Prerequisite: 2515 or permission of the instructor. Mr. Dworsky.
The concepts, processes, and techniques of regional, multipurpose river basin planning and development. The case study method, including the preparation of an integrated, comprehensive report for the study area.

2547 Environmental Policy Analysis (g). Fall. Credit three hours. Prerequisite: 301, 2518 or 2618, 9360, or permission of instructor. Mr. Loucks.
Current research topics concerning the application of economic and simulation techniques to the definition and evaluation of public policy alternatives for managing air, land, and water resources and the material and energy wastes released into the environment. The influence of technologic, economic, and political uncertainty will be emphasized. Each student will be expected to select a particular environmental management problem and structure models or methods for analyzing alternative solutions.

2591 Design Project in Water Resource Systems Engineering or in Sanitary Engineering (g). On demand. Credit variable. Prerequisite: 2501 or 2502 or equivalent. Staff.
The student will elect or be assigned problems in the design of water and wastewater treatment processes or plants; wastewater disposal systems; water quality control systems, water resource development or management systems; or laboratory apparatus of special interest.

2592 Sanitary Engineering Research (g). On demand. Credit variable. Prerequisites will depend on the particular investigation to be undertaken. Staff.
For the student who wishes to study a special topic or problem in greater depth than is possible in formal courses.

2593 Environmental Protection and Management Colloquium or Seminar (u,g). Fall and spring. Credit one to two hours. Required of graduate students majoring or minoring in sanitary engineering. Open to undergraduates with permission of the instructor.
Presentation and discussion of current topics and problems in sanitary engineering and water resources engineering.

2594 Special Topics in Sanitary and Water Resource Systems Engineering (g). Offered on demand. Hours and credit variable. Staff.
Supervised study in special topics not covered in formal courses.

2603 Engineering Economics and Systems Analysis (u). Spring. Credit three hours. Mr. Lynn.
Principles and techniques for making decisions about the economic aspects of engineering projects; choosing between alternatives; criteria for making decisions; time value of money; economic selection and operation; retirement and replacement; introduction to estimating costs of construction. Introduction to systems analysis as an approach to providing information for public policy decision making, including: optimization, mathematical programming, and integration of technological and social aspects of engineering projects.

2605 The Law and Environmental Control (g). Fall. Credit three hours. Prerequisite: permission of the instructor. Designed for seniors and graduate students. Mr. Bereano.
An introduction to the structure and operation of the legal system and an investigation of the manner in which that system may handle environmental problems. The interaction of law and science; regional problems and political jurisdictional boundaries; the police power of the states; statutory law and case law; the judicial function; the nature and functions of the administrative agencies; environmental regulation; recent environmental case law; the interstate compact.

2606 Seminar in Technology Assessment (u,g). Spring. Credit three hours. Mr. Bereano and others.
An interdisciplinary seminar dealing with the social consequences of future technological development and the means by which technology can be guided in socially beneficial directions. Student-faculty task forces will organize to undertake projects exploring aspects of technology assessment theory and methodology, perform simple assessments, or investigate questions pertaining to the design and functioning of institutions to perform such tasks.

2611 Microeconomic Theory I (u,g). Fall. Credit four hours. Prerequisite: permission of instructor. Mr. Falkson.
Scope and method of economics. Individual and market demand. Cost and supply curves. Competitive equilibrium. Dynamic adjustment and stability. Monopoly. Price discrimination. Economic efficiency. Applications of price theory to public policy in the areas of agriculture, taxation, and governmental regulation of public utilities. Operation of public enterprises. The theory of production. Production functions and suboptimization at the engineering level. Marginal productivity theory of factor demand. Theory of derived demand. Monopsony. Minimum wage laws. Labor unions. The linear programming approach to the theory of production. Systems analysis of public projects.

2612 Microeconomic Theory II (u,g). Spring. Credit four hours. Prerequisite: 2611. Mr. Falkson.
The theory of imperfect competition. Oligopoly theory. Game theory. Monopolistic competition. Spatial competition. The theory of consumer behavior. Cardinal utility theory. Ordinal utility theory. Revealed preference theory and index numbers. Consumer surplus. Intertemporal choice. Uncertainty. Welfare economics. External effects. General equilibrium. Input-output analysis. Materials balance and recycling.

[**2613 Macroeconomic Theory (u,g).** Credit four hours. Prerequisite: 2611, 2612. Mr. Falkson. Not offered in 1971–72.
National income accounting. Money and banking. Federal Reserve policy. Classical model of employment. Inflation. Keynesian model of income determination. Theories of consumption and investment. Fiscal policy. Foreign trade. Dynamic macro models. Accelerator-multiplier interaction. Harod-Domar growth model. Neoclassical growth models. Population growth. Regional development models.]

2617 Public Systems Analysis I (u,g). Fall. Credit one to two hours. Prerequisite: 9320 or 9522, which may be taken concurrently.

An introduction to the use of systems analysis in structuring public decision problems.

2618 Public Systems Analysis II (u,g). Spring. Credit three hours. Prerequisite: 2611, 2617, 9320 or 9522, 9160 or 9460, and 9321 or 9523, which may be taken concurrently.
A survey of the applications of systems analysis techniques to public sector problems. Some of the areas to be considered are transportation systems, water resources, and environmental quality management.

2619 Environmental Systems Analysis (u,g). Fall. Credit three hours. Prerequisite: 2618.
Application of systems analysis and economics to water resource and environmental quality management. Design and operation of water resources systems. Evaluation of public policy alternatives for air, land, and water resources and the material and energy wastes released into the environment. Development of deterministic and stochastic models for steady-state and dynamic conditions.

2620 Transportation Engineering (u,g). Fall. Credit three hours. Mr. Fisher.
Transportation systems analysis; traffic generation, distribution, and assignment models; modal split models. Elements of traffic flow theory and congestion analysis. Terminals and transfer delays. Physical environment evaluation, including route location and use of aerial photography. Transport economics and current policy issues. Technological and economic characteristics of current transportation modes.

2621 Urban Transportation Planning I (u,g). Fall. Credit three hours. Prerequisite for most other courses in transportation area. Prerequisite: 2611. Messrs. Meyburg and Stopher.
The urban transportation problem, its roots, manifestations and implications; the systems analysis approach to transportation; the demand and supply side of transportation; the urban transportation planning process; generation of alternatives and their evaluation; introduction to decision theory.

2622 Multivariate Analysis Methods in Transportation (u,g). Fall. Credit four hours. Prerequisite: 9170. Mr. Stopher.
A course in multivariate methods for statistical model building in transportation and other urban systems. Linear and nonlinear regression analysis, weighted regression, canonical correlation, factor analysis, simultaneous equations methods, discriminant analysis, probit analysis, and logit analysis. Applications to transportation demand modelling.

2623 Urban Transportation Planning II (u,g). Spring. Credit three hours. Prerequisite: 2621, 2622, 2611, permission of instructor. Mr. Stopher.
Advanced study of conventional models of travel demand in transportation studies, including residential and nonresidential trip generation; Fratar, Gravity and opportunity models of trip distribution; trip-end and trip-interchange modal split; network assignment. New methods of travel demand modelling, including spatial distribution theories, "abstract mode" models, and individual behavior theories. The propagation of errors in models.

2624 Transportation Systems Analysis (u,g). Spring. Credit three hours. Prerequisite: 9360, 9522, 2611, 2621. Mr. Meyburg.
Techniques of systems analysis as applied to the physical planning, operation, and financing of transportation facilities. Wherever applicable, mathematical models of transportation processes are used to examine questions related to the development of optimal public policy decisions in the area of transportation. Attention is given to analysis of single and multimodal forms of transportation. Methods of mathematical programming, simulation, and stochastic processes are employed.

[**2631 Construction Management (g).** Fall. Credit three hours. Prerequisite: permission of instructor. Not offered in 1971–72.
Planning and operation of construction projects by the civil engineer using modern management techniques. Coordinated organization and control of men, materials, and machines; scheduling, estimating, purchasing, inventory, selection and training of employees, cost control, accident prevention. Operations Management (BPA 127) is suggested as an alternate.]

[**2632 Construction Systems Analysis (g).** Spring. Credit three hours. One three-hour meeting per week. Prerequisite: 9522 or consent of instructor. Mr. Lynn. Not offered 1971–72.
A project-oriented seminar on the identification of important construction problems and the application to them of systems analysis, designed to give the student a deep experience in the formulation, conceptualization, and mathematical modeling of construction systems as a basis for rational decision-making. Normally a single problem to be attacked is agreed upon by students and instructors. Typical problems have been (1) earth-moving and equipment scheduling on a major stretch of Interstate Highway 81, and (2) inventory control of construction projects.]

2640 Traffic Flow Theory (u,g). Spring. Credit three hours. Prerequisite: 2621.
Study of various mathematical theories of traffic flow. Microscopic models (car following models). Macroscopic models (kinematic wave theory). Stochastic properties of traffic flow at low density. Probability models for traffic lights and optimal control of signalized intersections. Traffic flow on transportation networks. Application to traffic assignment. Traffic network simulation system.

2641 Airport Planning and Operations (u,g). Spring. Credit three hours. Prerequisite: 2621. Mr. Meyburg.
Terminal access; location and site selection; terminal design and operations; metropolitan air transit systems; environmental impact of airport location; air traffic flow analysis; air traffic control; aircraft technology.

[**2643 Design and Planning of Mass Transportation (u,g).** Spring. Credit three hours. Prerequisite: 2621. Mr. Stopher. Not offered in 1971–72.
A study of mass transportation of the past and present; innovative forms of mass and individual transportation in urban areas. The financing and organization of mass transportation; the "free transit"-fares dilemma. Planning for mass transportation: special applications; implementation of plans; planning transportation in new towns.]

2644 Transportation Systems Evaluation (u,g). Spring. Credit three hours. Prerequisite: 2611, 2621. Mr. Stopher.
Economic evaluation techniques; measures of effectiveness; cost-effectiveness evaluation; definition of goals, objectives, and criteria for transportation planning; impact analysis and evaluation.

2680 Environmental Control Workshop (g). Spring. Credit one to three hours by arrangement with instructor. Mr. Lynn.

Students interested in research topics dealing with control of the environment (with special emphasis on biological and ecological aspects) are encouraged to participate in this workshop. Topics which have been discussed in previous workshops include human population control, control of pest and parasite populations, study of species' strategic use of food supply, control of populations by use of predators, and host-parasite systems. Additional topics will be developed in the workshop.

2691 Public Systems Analysis Design Project (g). On demand. Credit variable. Prerequisite: permission of instructor. May extend over two semesters. Staff.
Design of feasibility study of public systems, supervised and assisted by one or more faculty advisers. Individual or group participation. Final report required.

2692 Public Systems Analysis Research (g). On demand. Credit variable. Prerequisite: permission of the instructor. Preparation must be suitable to the investigation to be undertaken. Staff.
Investigation in depth of particular public systems problems.

2693 Public Systems Planning and Analysis Colloquium (u,g). Either term. Credit one hour.
Lectures in various topics related to public systems planning and analysis.

2694, 2695 Special Topics in Public Systems Planning and Analysis (g). On demand. Credit variable. Staff.
Supervised study, by individuals or small groups, of one or more specialized topics not covered in regular courses.

2701 Structural Engineering I (u). Fall. Credit three hours. Three lectures, one two-hour period. Prerequisite: Mechanics 1021. Evening preliminary examinations. Staff.
First course in a three-course sequence of structural theory, behavior, and design. Basic structural concepts. External forces on simple structures. Behavior under load of metal members (beams, compression members, and beam-columns), including elastic and inelastic buckling. Properties and behavior of reinforced concrete and behavior of reinforced concrete beams, columns, and beam-columns. Deflections by moment area method.

2702 Structural Engineering II (u). Spring. Credit four hours. Three lectures, one two-hour period. Prerequisite: 2701. Evening preliminary examinations. Staff.
Cable structures and prestressing concepts. Deflections and analysis of indeterminate structures by method of virtual work. Castigliano's theorems, moment distribution, and matrix structural analysis. Collapse theory and plastic design concepts. Structures subjected to moving loads. Applications to steel and concrete structures.

2703 Structural Engineering III (u). Fall. Credit three hours. Two lectures, one two-hour period. Prerequisite: 2702. Will not be offered after fall term, 1971. Staff.
Continuation of indeterminate analysis topics of 2702, including Castigliano's theorems, moment distribution, and matrix structural analysis. Collapse theory and plastic design concepts. Structures subjected to moving loads (influence lines). Applications to steel and concrete structures.

2704 Structural Design (u). Spring. Credit three or four hours. Two lectures, one or two periods of two hours. Prerequisite: 2703. Staff.
Comprehensive design project drawing on material from previous courses in structures and materials. Additional design topics such as approximate analysis and preliminary design, choice of structural form, shell structures, timber structures, structural models, connections, and composite construction.

2705 Structural Behavior Laboratory (u). Fall and spring. Credit one or two hours. May be taken concurrently with 2701, 2702, 2703, or 2704. Mr. White.
A laboratory course on behavior of structures, utilizing small-scale models. Elastic, inelastic, and nonlinear behavior of structural components and systems, including beams, beam-columns, trusses, frames, grids, plates, and shells in both metal and reinforced concrete. Dynamic behavior. Individual projects.

2710 Strength of Structures (u,g). Fall. Credit three hours. Three recitations. Prerequisite: 2703 can be taken concurrently; undergraduates must have grade B or better in 2701 and 2702. Mr. Winter.
Analysis of two- and three-dimensional stress and strain. Theories of failure of ductile and brittle materials. Microstructure of materials. Structural materials under load, strain hardening. Bauschinger effect, residual stresses, hysteresis, stress concentration, brittle fracture, creep, alternating stress. Design for fatigue. Stresses beyond the elastic limit. Inelastic behavior of steel and reinforced concrete structures. Critical discussion of recent research and current design specifications.

2711 Buckling: Elastic and Inelastic (u,g). Spring. Credit three hours. Prerequisite: 2710. Mr. Winter.
Analysis of elastic and plastic stability. Determination of buckling loads and post-buckling behavior of columns. Solid and open web columns with variable cross-section. Beam columns. Frame buckling. Torsional-flexural buckling. Lateral strength of unbraced beams. Buckling loads and postbuckling behavior of plates, shear webs, and cylindrical shells. Critical discussion of current design specification.

2712 Advanced Structural Analysis (u,g). Fall. Credit three hours. Three lectures. Prerequisite: 2703, coregistration in Computer Science 311; undergraduates must have grade B or better in 2701, 2702, and 2703. Mr. Nilson.
Stability, determinacy, redundancy of structures. Approximate methods of analysis. Force, displacement, and transfer matrix methods of matrix structural analysis. Development of space frame element equations, including distributed loads and thermal strain effects. Methods of solution: direct and iterative, tridiagonalization, partitioning, and special transformations. Analysis techniques for tall buildings and other special problems.

2713 Finite-Element Analysis (u,g). Spring. Credit three hours. Three lectures. Prerequisite: 2712. Mr. Gallagher.
Theoretical and conceptual bases for formulation of finite-element representations in continuum mechanics. Development of element relationships for structural analysis of plates, shells, and solids. Extension of element- and system-solution techniques to deal with problems in elastic stability, inelastic deformaton, finite displacements, dynamic response, and other special behavior mechanisms.

2714 Structural Model Analysis and Experimental Methods (u,g). Spring. Credit three hours. Two lec-

tures, one two-hour period. Prerequisite: indeterminate analysis. Mr. White.
Dimensional analysis and principles of similitude. Direct model analysis, including materials, fabrication, loading, and instrumentation techniques. Basic techniques of experimental stress analysis. Confidence levels for model results. Laboratory projects in elastic behavior and ultimate strength of model structures.

2715 Probabilistic Concepts in Structural Engineering (u,g). Spring. Credit three hours. Offered in alternate years, beginning in 1971–72. Mr. Sexsmith.
Introduction probability concepts pertaining to engineering design and reliability; probabilistic models; inference techniques; decision analysis; stochastic processes; applications in structural safety decisions and structural random vibration.

2716 Concrete Structures I (u,g). Fall. Credit three hours. Three lectures. Prerequisite: 2703 can be taken concurrently; undergraduates must have grade B or better in 2701 and 2702. Mr. Nilson.
Analysis, design, and behavior of prestressed concrete structures; beams, slabs, composite construction, continuous beams and frames, tension and compression members; deflection analysis, end zone stresses, detailing, losses, efficiency. Design of concrete shells: shells of revolution, hyperbolic paraboloids.

2717 Concrete Structures II (u,g). Spring. Credit three hours. Three lectures. Prerequisite: 2703; undergraduates must have grade B or better in 2701, 2702, and 2703. Mr. Nilson.
Analysis, design, and behavior of reinforced concrete structures; safety considerations, deflection analysis, crack control; beams, columns, slabs, continuous frames, flat plates, flat slabs, composite construction; limit analysis and yield line theory. Design of concrete shells: folded plates and cylindrical shells.

2718, 2719 Behavior and Design of Metal Structures (u,g). Fall and spring. Credit three hours each term. Prerequisite: 2703 can be taken concurrently; undergraduates must have grade B or better in 2701 and 2702. Mr. McGuire.
Contemporary methods for analyzing and designing metal structures. Behavior of structural elements and frames. Selected design applications from the fields of steel plate structures, bridges, suspension systems, lightweight structures.

2720 Shell Theory and Design (u,g). Fall. Credit three hours. Prerequisite: Mathematics 294 or equivalent and consent of instructor. Mr. Gergely.
Differential geometry of surfaces. Bending and membrane theory of shells. Analysis and design of cylindrical shells, domes, paraboloids. Application to reinforced concrete roofs and pressure vessels. Stability of certain types of shells.

2722 Structural Design for Dynamic Loads (u,g). Spring. Credit three hours. Prerequisite: Mathematics 294 or equivalent and consent of instructor. Mr. Gergely.
Equations of motion and vibration of simple systems. Numerical, energy, and matrix methods of analysis of multiple degree systems. Analysis and design of structures for ground disturbances, including inelastic effects.

2730–2731 Transportation Structures (u,g). (Same as Theoretical and Applied Mechanics 1730–1731.) Fall and spring. Credit three hours. To be offered in alternate years, beginning in 1971–72. Prerequisite: Mechanics 1021. Messrs. Boley and Gallagher.
Treatment of structural design aspects of land, sea, and air vehicles. Description of applicable design specifications, design environments, materials failure criteria, forms of construction, and methods of structural analysis. Each student will be required to develop a term paper on a facet of the course.

[**2732 Optimum Structural Design (g).** Fall. Credit three hours. Prerequisite: 2617 or equivalent and consent of instructor. Not offered in 1971–72.
Classification of optimum structural design problems; merit functions and design variables. Fully stressed design. Mathematical programming methods in optimum structural design, including linear programming, gradient projection, and penalty function procedure. Classical methods, including Lagrangian multipliers and variational concepts. Application to truss and beam design situations is emphasized.]

2751 Engineering Materials (u). Spring. Credit three hours. Two lectures, one laboratory. Mr. Slate.
Engineering properties of concrete; engineering properties of steel, wood, and other selected structural materials; physico-chemical properties of soils, concrete, and bituminous materials. Design characteristics and significance of test results of materials used in engineering works. Extensive laboratory testing and report writing.

2752 Advanced Plain Concrete (g). Fall. Credit three hours. Two lectures plus conference. Prerequisite: 2751 or equivalent. Mr. Slate.
Topics in the field of concrete, such as history of cementing materials, air-entrainment, light weight aggregates, petrography, durability, chemical reactions, and properties of aggregates. Relationships among internal structure, physical properties, chemical properties, and the mechanical properties of interest to the design and construction engineer.

2753 Structure and Properties of Materials (g). Spring. Credit three hours. Two lectures plus conference. Open to graduate students in engineering or the physical sciences or to undergraduates by consent of the instructor. Mr. Slate.
Internal structure of materials ranging from the amorphous to the crystalline state. Forces holding matter together versus forces causing deformation and failure. Correlation of the internal structures of materials with their physical and mechanical properties. Applications to various engineering materials.

2757 Civil and Environmental Engineering Materials Project (g). On demand. Credit one to six hours. Mr. Slate.
Individual projects involving civil engineering materials.

2758 Civil and Environmental Engineering Materials Research (g). On demand. Hours and credit variable. Mr. Slate.
Individual assignments, investigations and/or experiments with civil engineering materials.

2790 Planning of Structural Systems (u,g). Fall. Credit three hours. Prerequisite: 2703 can be taken concurrently, and consent of instructor. Mr. Peköz.
Functional, structural, and other considerations in the planning and selection of structural systems. Probabilistic description of loading and strength. Preliminary design—estimating overall dimensions and weights, proportioning of members and joints—and optimization. Preliminary analysis of frames, trusses, plates, and shells. Erection, construction, and stress control considerations. Computer structural analysis. Case studies with the participation of practicing engineers.

2791 Design Project in Structural Engineering (g). (Meets project requirement for M.Eng. degree.) Fall and spring. Credit one hour fall and three hours spring; both terms required. Coregistration in 2790 during fall semester also required. Staff.
Comprehensive design projects by design teams. Formulation of alternate design proposals, including economics and planning, for a given situation and complete design of the best alternate. Determination of construction costs and preparation of sketches and drawings. Presentation of designs by oral and written reports.

2792 Research in Structural Engineering (g). On demand. Hours and credit variable. Staff.
Students wishing to pursue one particular branch of structural engineering further than can be done in any of the regular courses may elect work in this field. The prerequisite courses depend upon the nature of the work desired. The work may be an investigation of existing types of construction, theoretical work with a view of simplifying present methods of design or proposing new methods, or experimental investigation of suitable problems.

2793 Structural Engineering Seminar (u,g). Fall and spring. Credit one to three hours. Open to qualified seniors and graduate students. Staff.
Preparation and presentation of topics of current interest in the field of structures for informal discussion.

2794 Special Topics in Structural Engineering (g). On demand. Hours and credit variable. Staff.
Individually supervised study in one or more of the specialized topics of civil engineering, such as tanks and bins, suspension bridges, towers or movable bridges, which are not covered in the regular courses. Independent design or research projects may also be selected.

Computer Science

201 Survey of Computer Science (u). Fall. Credit three hours. M W F 9:05.
Introduction to the structure and use of the modern computer. Intended to be an overview of the material; emphasis is on nonnumeric computer applications, such as information retrieval, language processing, and artificial intelligence. A limited introduction to programming in a problem-oriented language is included.

202 Computers and Programming (u). Either term. Credit three hours. Prerequisite: some programming experience in an algebraic language. M W 9:05 or T Th 10:10; laboratory M T W Th or F 2:30–4:25.
Intended as a foundations course in computer programming and machine organization. Algorithms and their relation to computers and programs. A procedure-oriented language: specification of syntax and semantics, data types and structure, statement types, program structure. Machine organization: components, representation of data, storage addressing, instructions, interpretation cycle, interrupts. Some assembly language programming. Programming and debugging problems on a computer are essential parts of this course.

203 Discrete Structures (u). Fall. Credit three hours. Prerequisite: 201 or 202. M W F 1:25.
Fundamental mathematical concepts relevant to computer science. Set algebra, mappings, relations, partial ordering, equivalence relations, congruences. Operations on a set, groups, semigroups, rings and lattices, isomorphism and homomorphism, applications to automata and formal languages. Boolean algebra, applications to switching theory and decision tables. Directed and undirected graphs, subgraphs, chains, circuits, paths, cycles, graph isomorphism, application to syntactic analysis and computer program analysis.

222 An Introduction to Numerical Analysis (u). Spring. Credit three hours. Prerequisite: grade of B or better in Mathematics 122, and Computer Science 202 or 311 or consent of instructor. M W F 10:10.
The course will provide a leisurely paced yet rigorous introduction to a subfield of numerical analysis. The lectures are intended to provide motivation for the study of the chosen topic rather than to merely survey the known results in the area. Examples of possible topics are: approximation theory, solutions of ill-conditioned linear problems, numerical solutions of differential equations, quadrature theory, roots of nonlinear equations.

305 The Computerized Society (u). Fall. Credit three hours. T Th 10:10.
A seminar-style course designed to bring the perspectives of the sciences, social sciences, and humanities to the question of the impact of computers on society. Enrollment will be limited to thirty students of varied backgrounds who show an interest in the present-day influences of computers on human life and the future alternatives in the application of computers to society. Topics to be discussed include: the potentialities and limitations of the computer—the popular view *versus* the computer scientist's view; man and the machine—the identity crisis; human privacy and the national data banks; human decision making *versus* military and industrial automation; the knowledge explosion and information-retrieval systems; technological and occupational obsolescence—what price for progress?; social structure in the year 2000.

311 Introduction to Computer Programming (u). Either term. Credit two hours. T Th 11:15.
Notations for describing algorithms, analysis of computational problems. Applications of the (FORTRAN IV, PL/I) programming language to solve simple numerical and nonnumerical problems using a digital computer.

385 Introduction to Automata Theory (u). Spring. Credit three hours. Prerequisite: 203 or Mathematics 222 or 294. M W F 10:10.
Models of abstract computing devices. Finite automata and regular expressions and sets. Input-output experiments, nondeterministic machines, parallel and sequential realizations, and algebraic structure theory. Pushdown automata and context-free languages. Closure properties and decision problems. Turing machines and recursively enumerable sets. Universal Turing machines, the halting problem, decidability.

401 Introduction to Computer Systems and Organization (u,g). Either term. Credit four hours. Prerequisite: Mathematics 221 or 293 or consent of instructor. T Th 11:15; laboratory, M T W Th or F 2:30–4:25.
Characteristics and structure of digital computers as hardware units. Representation of data, addressing of data, index registers, indirect and base-plus-displacement addressing. Codes for error detection and corrections. Introduction to computer microstructure, gates, flip-flops, adders. Storage and peripheral hardware and their characteristics, the input-output channel, interrupts. Assembly language programming:

format and basic instructions, the assembly process, loops and indexing, data types, subroutines, macros. Brief description of operating systems, loaders, interpreters, and compilers. Programming and debugging assembly language programs on a computer are an essential part of this course.

[**404 Advanced Computer Programming (g).** Spring. Credit four hours. Prerequisite: 202 or 401 or consent of the instructor. Not offered in 1971–72.
Intended for students who wish to learn computer programming for eventual use in professional systems programming or advanced applications. To develop this ability, the basic logical and physical structure of digital computers is considered, and the applicability and limitations of this structure are studied through many examples and exercises. The approach, therefore, is not a theoretical one, but rather an engineering one, in which techniques are emphasized. The students are expected to participate in a large systems programming design and implementation effort.]

409 Data Structures (g). Fall. Credit four hours. Prerequisite: 202 or 401 or the equivalent. T Th 9:05, W 2:30.
Data structures, relations between data elements, and operations upon data structures. Bits, bytes, fields, arrays, stacks, trees, graphs, lists, strings, records, files, and other forms of data structures. Primitive operations, accessing techniques, and storage management techniques appropriate to each class of data structures. Sorting and searching techniques, symbol table structures. Data structures in programming languages, retrieval systems, and data management systems. Formal specification of classes of information structures.

411 Programming Languages (g). Fall. Credit four hours. Prerequisite: 202 or 401 or consent of the instructor. M W F 1:25.
An introduction to the structure of programming languages. Specification of syntax and semantics. Properties of algorithmic list processing, string manipulation, and simulation languages: basic data types and structures, operations on data, statement types, and program structure. Macro languages and their implementation. Run-time representation of programs and data. Storage management techniques. Introduction to compiler construction.

412 Translator Writing (g). Spring. Credit four hours. Prerequisite: 411 or consent of the instructor. M W F 1:25.
Discussion of the models and techniques used in the design and implementation of assemblers, interpreters, and 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, compiler-compiler systems.

413 Systems Programming and Operating Systems (g). Fall. Credit four hours. Prerequisite: 409 or consent of the instructor. M W F 1:25.
The organization and software components of modern operating systems. Batch processing systems. Loaders, input-output systems, and interrupt handling. Descriptive schema for parallel processes; communication among parallel processes. Introduction to multiprogramming and multiprocessing systems. Addressing techniques, memory and instruction protection, procedure and data sharing; process scheduling, resource management; file organization, accessing, and management. Time-sharing systems. Case studies in multiprogramming, multiprocessing, and time-sharing. Additional topics such as job control languages and microprogramming. Projects involving the design and implementation of systems program modules.

[**415 Machine Organization (g).** Spring. Credit four hours. Prerequisite: 202, 401, or consent of the instructor. M W F 2:30. Not offered in 1971–72.
The design and functional organization of digital computers. Boolean algebra, elements of logical design, and computer components. Counters, shift registers, half and full adders, design of arithmetic units. Memory components, accessing and retrieval techniques, addressing structures, realization of indexing, and indirect addressing. Control unit structure, instruction decoding, synchronous and asynchronous control. Input-output channels, buffering, auxiliary memory structure, interrupt structures. Overall system organization, reliability, system diagnostics, system simulation.]

[**416 Operations Research Models for Computer and Programming Systems (g).** Spring. Credit four hours. Prerequisite: 411 and a course in probability (e.g., Mathematics 371 or Engineering 9460), or consent of instructor. T Th 10:10, occasionally W 2:30. Not offered in 1971–72.
Modeling and analysis of computer hardware and software systems. Some applications of the theories and techniques of operations research to problems arising in computer systems design and programming. Operating systems design: resource allocation and scheduling. Queuing models for time-sharing and multiprogramming systems. Reliability of computer systems and computer networks. Statistical techniques for measuring systems performance. Simulation of hardware and software; systems balancing. Applications of stochastic processes and inventory theory, e.g., file organization and management, models of computer center operation. Mathematical programming techniques applied to hardware configuration selection. Students will be expected to program and analyze a model which can be applied to a problem of hardware or software design.]

420 Computer Applications of Numerical Analysis (g). Fall. Credit four hours. Prerequisite: Mathematics 222 or 294 and Computer Science 311 or equivalent programming experience. (Graduate students in computer science are urged to take 421–422 instead of this course.) M W F 10:10.
Modern computational algorithms for the numerical solution of a variety of applied mathematics problems are presented, and students solve current representative problems by programming each of these algorithms to be run on the computer. Topics include numerical algorithms for the solution of linear systems; finding determinants, inverses, eigenvalues and eigenvectors of matrices; solution of a single polynomial or transcendental equation in one unknown; solution of systems of nonlinear equations; acceleration of convergence; Lagrangian interpolation and least squares approximation for functions given by a discrete data set; differentiation and integration; solution of ordinary differential equations; initial value problems for systems of nonlinear first-order differential equations, two-point boundary value problems; partial differential equations: finite difference grid technique for the solution of the Poisson equation.

421–422 Numerical Analysis (g). Fall and spring. Credit four hours a term. Prerequisite: Mathematics 412, 416, or 422 or consent of instructor. M W F

9:05; laboratory, one hour per week, time to be arranged.
A mathematical analysis of numerical methods from the areas of solution of linear systems of equations, matrix inversion, eigenvalue and eigenvector determination, nonlinear equations, polynomial approximation, interpolation, differentiation, integration, ordinary and partial differential equations. Practical experience will be gained in the laboratory.

435 Information Organization and Retrieval (g). Spring. Credit four hours. Prerequisite: 401 or the equivalent. T Th 9:05, occasionally W 2:30.
Covers all aspects of automatic language processing on digital computers, with emphasis on applications to information retrieval. Analysis of information content by statistical, syntactic, and logical methods. Dictionary techniques. Automatic retrieval systems, question-answering systems. Evaluation of retrieval effectiveness.

441 Mathematical Symbol Manipulation (g). Spring. Credit four hours. Prerequisite: 409 and some knowledge of discrete mathematics (e.g., 203, 485, or Mathematics 431). Hours to be arranged.
This course deals with arithmetic and algebraic algorithms and their implementation in a generalized computer system. The emphasis will be on symbolic rather than numeric techniques for solutions to the problems. For each algorithm, computing times will be derived and analyzed. Among the topics to be covered are infinite precision integer arithmetic, modular arithmetic, operations on multivariate polynomials and rational functions, such as symbolic integration and exact factorization over several fields, and exact solution of linear systems.

485 Theory of Automata I (g). Fall. Credit four hours. Prerequisite: 203 or 401, or mathematics and some programming experience, or consent of the instructor. M W F 11:15.
Automata theory is the study of abstract models of computation, both computing devices and algorithmic languages; their classification, structure, and computational power. Topics include finite state automata, regular expressions, decompositions of finite automata, Turing machines, random access machines and their abstract programming languages, halting problems, undecidability, universality, and Church's thesis.

486 Theory of Automata II (g). Spring. Credit four hours. Prerequisite: 485 or consent of the instructor. M W F 11:15.
Topics include context-free and context-sensitive languages and their relation to push-down and linearly bounded automata. Quantitative aspects of Turing machine computations: time and memory bounded computations with applications to language processing and classification of other automata and computations.

[**487 Formal Languages (g).** Fall. Credit four hours. Prerequisite: 486 or consent of the instructor. Not offered in 1971–72.
A study of formal languages, their processing and processors. Topics include regular, context-free, and context-sensitive languages: their recognition, parsing, algebraic properties, decision problems, recognition devices, and applications to computer and natural languages.]

[**488 Theory of Effective Computability (g).** Spring. Credit four hours. Prerequisite: 401, 485, Mathematics 481, or consent of the instructor. Not offered in 1971–72.
Turing machines and Church's thesis, universal Turing machines, unsolvability of the halting problem. Recursively enumerable sets, productive and creative sets, relative computability, the recursion theorem, Post's problem. Computational complexity hierarchies.]

[**517 Picture Processing (g).** Spring. Credit four hours. Prerequisite: 411 or consent of instructor. M W F 10:10. Not offered in 1971–72.
A study of computer graphics and digital picture analysis. Topics include display and digitization hardware, picture data structures, preprocessing and feature detection, the receptor-categorizer model of pattern recognition, linguistic methods in picture processing, mathematics of picture transformations, graphics programming languages and systems.]

521 Solutions of Nonlinear Equations and Nonlinear Optimization Problems (g). Spring. Credit four hours. Prerequisite: 422 or consent of instructor. M W F 10:10.
The course will emphasize the rigorous analysis of practical numerical algorithms for nonlinear problems. Sample topics are nonlinear functional analysis, nonlinear curve fitting, computationally convenient modifications of Newton's method and descent methods, applications to control theory and integral equations, constrained optimization.

523 Numerical Solution of Ordinary Differential Equations and Integral Equations (g). Fall. Credit four hours. Prerequisite: 422 or consent of the instructor. M W F 11:15.
Topics include solution of *n*th order nonlinear initial value problems and boundary value problems; single step methods; predictor-corrector techniques; stability, accuracy, and precision of methods; eigenvalue problems; solution of integral equations having constant or variable limits: finite difference and iterative methods; singular and nonlinear integral equations.

525 Numerical Solution of Partial Differential Equations (g). Spring. Credit four hours. Prerequisite: 523 or consent of the instructor. M W F 11:15.
General classification; solution by method of characteristics; finite-difference methods for hyperbolic and elliptic equations; parabolic equations in two dimensions; direct solution of elliptic finite-difference equations; iterative methods for the solution of elliptic equations; block methods for large systems; singularities in elliptic equations; stability in relation to initial value problems and nonlinear discretization algorithms.

[**527 Introduction to Approximation Theory (g).** Spring. Credit four hours. Prerequisite: 422 or consent of the instructor. M W F 10:10. Not offered in 1971–72.
The study of the characterization of best linear and nonlinear (L_p) approximations to real functions, the Remez algorithm, and best approximations to bounded linear functionals with applications to quadrature theory and optimal approximations.]

[**587 Computational Complexity (g).** Fall. Credit four hours. Prerequisite: 486 or 488 or consent of the instructor. T Th 9:05. Not offered in 1971–72.
General measures of computational complexity and methods of classifying computable (recursive) functions. Examples of topics include restricted Turing machines, time and memory bounded computations, and quantitative results about formal languages.]

589 Theory of Algorithms (g). Fall. Credit four hours. Prerequisite: 409 or 486. Hours to be arranged.

This course on the analysis and minimization of algorithms is primarily intended to acquaint students with recent research in this area. The material covered will include algorithms for high precision multiplication, matrix multiplication, evaluation of polynomials, discrete Fourier transforms, pattern matching, algebraic manipulation, sorting, finding medians, and manipulation of graphs. Emphasis will be on theoretical aspects of such algorithms with a view toward developing a theory of computation. Recent work of Cook, Winograd, Floyd, Strassen, Schonhage, and Knuth will be included.

590 Special Investigations in Computer Science (g). Fall and spring. Credit to be arranged. Prerequisite: consent of the registration officer of the Department. Hours to be arranged. Offered to qualified students individually or in small groups.
Directed study of special problems in the field of computer science.

591 Computer Science Graduate Seminar (g). Fall and spring. Credit one hour. For graduate students interested in computer science. Th 4:40–6. Staff, visitors, and students.
A weekly meeting for the discussion and study of important topics in the field.

611 Seminar in Programming (g). Either term. Credit four hours. Prerequisite: 411 or consent of the instructor.

621 Seminar in Numerical Analysis (g). Either term. Credit four hours. Prerequisite: consent of the instructor.

635 Seminar in Information Organization and Retrieval (g). Fall. Credit four hours. Prerequisite: 435.

681 Seminar in Automata Theory (g). Either term. Credit four hours. Prerequisite: 486 or consent of the instructor.

Digital Systems Simulation (Industrial Engineering 9580) (g). Fall. Credit three hours. Prerequisite: 401 and Operations Research 9470, or consent of the instructor.

Data Processing Systems (Industrial Engineering 9582) (g). Fall. Credit three hours. Prerequisite: 401 or consent of the instructor.

Switching Systems I (Electrical Engineering 4487) (g). Fall. Credit three hours. Prerequisite: Electrical Engineering 4322 or consent of the instructor.

Switching Systems II (Electrical Engineering 4488) (g). Spring. Credit three hours. Prerequisite: Electrical Engineering 4487 or the equivalent.

Electrical Engineering

The courses in electrical engineering are listed under the following headings: *Required Courses* (Systems Sequences; Electrophysics Sequences); *Elective and Graduate Courses* (Theory of Systems and Networks; Electronics; Power Systems and Machinery; Communications, Information, and Decision Theory; Radio and Plasma Physics and Electromagnetic Theory; General); and *Courses of Interest to Students in Other Curricula.*

Required Courses

Systems Sequence

4301 Analysis of Electrical Systems I (u). Fall. Credit four hours. Three lectures, one recitation-computing. Prerequisite: Electrical Science 242 and Mathematics 294 or equivalents. Mr. Carlin.
Kirchhoff Laws and network equations, topological methods in circuit analysis. Concept of state; equilibrium and state equations. Transient and steady-state response of networks to exponential excitations, impedance, and transfer functions. Properties of passive and active networks, introductory frequency domain circuit design and synthesis.

4302 Analysis of Electrical Systems II (u). Spring. Credit four hours. Three lectures, one recitation-computing. Prerequisite: 4301. Mr. Szentirmai.
Fourier series (response of linear systems to periodic excitation), Fourier integral (response of zero state linear systems to aperiodic excitation), the convolution integral (time domain response of linear systems), application to modulation methods, the single- and double-sided Laplace transform (complete response of linear systems). Time and frequency-domain relations.

4401 Random Signals in Systems (u). Fall. Credit four hours. Three lectures, one recitation-computing. Prerequisite: 4302 or equivalent. Mr. Berger.
Description of random signals and analysis of randomly excited systems. An introduction to the concepts of probability, random variables, expectation, random processes, and power spectra. Applications are drawn from the areas of communications, control, and pattern classification. At the level of *Probability, Random Variables and Stochastic Processes* by Papoulis.

Electrophysics Sequence

4311–4312 Electromagnetic Fields and Waves (u). Fall and spring. Credit four hours. Three lectures, one recitation-computing. Prerequisite: Physics 233 and 234 and Mathematics 294, or equivalent. Messrs. Farley and Brice.
Foundations of electromagnetic theory for static and dynamic fields, with applications to energy storage, propagation, and radiation. Topics treated will include Maxwell's equations, solution of electrostatic problems by separation of variables, Poynting's theorem; plane waves in isotropic dielectrics and conductors, energy in dispersive media, reflection and refraction of plane waves; transmission lines, waveguides, cavities; plane waves in anisotropic dielectrics; radiation and antennas. At the level of *Fields and Waves in Communication Electronics* by Ramo, Whinnery, and Van Duzer.

4411 Quantum Theory and Applications (u). Fall. Credit four hours. Three lectures, one recitation-computing. Prerequisite: 4311, 4312, or equivalent. Mr. Tang.
Introductory quantum mechanics with particular emphasis on those aspects related to understanding conduction phenomena in solids and the interaction of radiation and matter typically encountered with lasing systems. Wave-particle duality will be examined for the example of a free particle. The mechanics of the theory will be presented in terms of wave functions, operators, and solutions of the Schroedinger wave equation. Where possible one-dimensional models will be used, but special features of two- and three-dimensional models will be discussed. Topics will include angular momentum, spin, the antisymmetric nature of the electron embodied in the Pauli exclusion principle, tunnelling, electrons in periodic potentials, and atomic and molecular structure. The course level is that of *Basic Quantum Mechanics* by White, or *Introduction to Quantum Theory* by Park.

Elective and Graduate Courses

Of the following elective and graduate courses, certain ones may not be offered every year if the demand is considered to be insufficient.

Theory of Systems and Networks

4450 Bioelectric Systems (u,g). Spring. Credit three hours. Three lectures. Prerequisite: 4401 or Biology 423 or Physics 360 or equivalent. Messrs. Capranica, Kim, and Moraff.

Deals with the application of electrical systems techniques to biological problems. Electrical activity of nerve cells; generation and propagation of nerve impulse; voltage clamp technique, Hodgkin-Huxley model, and its phase-plane analysis; electrical excitability and transfer function of neuromuscular systems; synaptic transmission; models of nerve cells and control system analysis of oscillatory activity. Nerve nets: evoked activity; spontaneous activity; simulation and computer analysis. Functional neuroanatomy of brain; transfer characteristics of sensory receptors; sensory encoding and processing in the peripheral and central nervous systems; neural mechanisms for vision and hearing.

4453 Introduction to Biomechanics, Bioengineering, Bionics, and Robots (u,g). (Same as Theoretical and Applied Mechanics 1801.) Fall. Credit three hours. Prerequisite: elementary dfferential equations, linear algebra, and probability; or consent of the instructor. Mr. Block.

For course description, see Theoretical and Applied Mechanics 1801.

4475 Active and Digital Network Design (u,g). Fall. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: 4302. Mr. Ku.

Introduction to network synthesis in terms of immittance and scattering parameters. Design of passive filters and matching networks. Active RC filter synthesis using negative-impedance converters (NIC), gyrators, and controlled sources. State-variable synthesis techniques using operational amplifiers. Practical realizations of active RC filters and sensitivity considerations. Active 2-port network theory and design of transistor amplifiers (bipolar and FET). Negative-resistance amplifiers using tunnel diodes and varactors. Introduction to digital signal processing and discrete-time network design. Z-transform and the discrete Fourier transform (DFT). Design of nonrecursive and recursive digital filters. Realizations of digital processing algorithms by either software procedures or hardware implementations. The fast Fourier transform (FFT) algorithms. Topics for the optional laboratory session: design and construction of passive and active filters based on analytical and computer-aided techniques using available computer programs; transistor (bipolar and FET) amplifier design using measured scattering parameters; simulation and hardware implementation of digital filters; computational realizations of DFT and FFT algorithms.

4478 Computer Methods in Electrical Engineering (u,g). Spring. Credit four hours. Prerequisite: 4302. Open to qualified juniors with consent of instructor. Graduate students with a special interest in this area should consider preceding this course by Computer Science 222 or 420. Mr. Pottle.

This course is designed to present modern techniques for solving electrical engineering problems on the digital computer. Emphasis is on efficiency (minimizing operation counts) and numerical stability rather than on theoretical implications. The laboratory session is used for experimenting with algorithms in an interactive environment.

Solution of linear and nonlinear algebraic equations; finding eigenvalues and eigenvectors; rootfinding; interpolation and extrapolation; integration; solution of ordinary differential equations; random number generators. Parameter optimization. Computer hardware and software considerations in implementing algorithms. Applications to power systems, control systems, circuit design, semiconductor devices, communication systems.

4503 Theory of Linear Systems (g). Fall. Credit four hours. Three lectures. Prerequisite: 4401 or consent of instructor. Mr. Pottle.

The state-space model for linear systems. Properties of ordinary linear differential equations. Fundamental and transition matrices. Matrix exponential functions, the Cayley-Hamilton theorem, and the Jordan form. Time invariant and time-varying network and system response. Controllability, observability, stability. Realizability of linear causal systems and applications of Fourier, Laplace, Hilbert transforms. Paley-Wiener theorem. Distributed systems. At the level of *Introduction to Linear System Theory* by Chen.

4504 Theory of Nonlinear Systems (g). Spring. Credit four hours. Three lectures. Prerequisite: 4503, 4501, 4571 or consent of instructor. Mr. Ku.

Analysis of first- and second-order nonlinear systems with applications. Phase-plane analysis of autonomous systems; singular points, limit cycles, and equilibrium states; theories of Bendixson, Lienard, and Poincare; relaxation behavior in the phase plane; perturbation theory, existence, convergence, and periodicity of perturbation series; methods of van der Pol and of Krylov and Bogoliubov. Forced nonlinear systems, harmonics, subharmonics, jump phenomena, and frequency entrainment; periodic systems, Floquet theory, Mathieu-Hill theory, applications to the stability of nonlinear systems and to parametrically excited systems.

4507–4508 Random Processes in Electrical Systems (g). Fall and spring. Credit four hours. Three lectures. Messrs. Berger and Fine.

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. Moment 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 processes, correlation functions, spectra; Bochner and Wiener-Khinchin theorems. Continuity, integration, and differentiation of sample functions. Hilbert space approach to optimum filtering and prediction. Spectral representation, orthogonal series representations. Markov chains and processes. Linear and nonlinear transformations of random processes.

[**4571 Network Analysis (g).** Fall. Credit four hours. Three lectures. Not offered in 1971–72.

Introduction to network topology. Network formulation for computer-aided analysis. State-space techniques for time-invariant and time-varying networks. Scattering, immittance, hybrid formalisms. Nonreciprocal and active network properties. Scattering and realizability theorems for multiport networks. At the level of

Network Theory: An Introduction to Reciprocal and Non-Reciprocal Circuits by Carlin and Giordano.]

4572 Network Synthesis (g). Spring. Credit four hours. Three lectures. Prerequisite: 4571 or 4503, or consent of instructor. Mr. Carlin.
Physical basis for network techniques in lumped and distributed systems deduced from linearity, time invariance, and power-energy constraints. Generalized, bounded real and positive-real functions and matrices and the theory of physical realizability. Applications to insertion-loss synthesis, synthesis of n-ports, design of transmission line filters and equilizers. Rc-lines. Gain-bandwidth theory of active devices. Synthesis of active networks.

4575 Computer Aided Network Design (u,g). Fall. Credit four hours. Three lectures. Prerequisite: 4302. Mr. Szentirmai.
Frequency and time domain analysis of large linear circuits. State-variable and matrix techniques. D.C. and transient analysis of nonlinear circuits. Tolerancing and sensitivity calculations, adjoint network approach. General formulation of computerized design methods in time or frequency domains. Unconstrained and constrained optimization methods and computer programs. Modelling of circuits. Filter and active RC circuit synthesis methods. Methods of eliminating numerical sensitivity problems. Implementation of algorithms for cascading active and digital circuits.

Electronics

4412 Solid State Physics and Applications (u,g). Spring. Credit four hours. Three lectures, one recitation. Prerequisite: 4411 or equivalent. Mr. Frey.
Introduction to solid state physics with emphasis on application to electronic devices: Crystal structure and symmetries, Brillouin zone representation of periodic structures, free-electron theory of conductivity, Drude theory of electrical conductivity, band theory; semiconductors, semiconductor devices; dielectric properties of solids, magnetism, and superconductivity. At the level of *Electronics of Solids* by Beam.

4430 Introduction to Lasers and Optical Electronics (u,g). Spring. Credit four hours. Two lectures, one lecture-recitation, one laboratory. Prerequisite: 4312, 4411, or equivalents such as Applied Physics 8155, 8156, and Physics 443. Messrs. Wolga and McFarlane.
An introduction to stimulated emission devices such as masers, lasers, and optical devices based on linear and nonlinear responses to coherent fields. The material discussed will be based on quantum mechanical results but will employ phenomenological theories and will stress applications to modern devices. Subjects covered will include: propagation of rays, spherical waves, and gaussian beams; microwave and optical resonators and their field characteristics; interaction of matter and radiation; absorption and amplification; threshold for oscillation, rate equations, and output power; specific laser and maser systems; harmonic generation and optical mixing; modulators; parametric converters; detectors; elements of holography. The laboratory will be used to illustrate and elaborate on specific lecture material. Laboratory experiments will include: atom, ion, molecular, and solid state laser oscillators and their characteristics; mode properties of coherent optical fields; harmonic generation; optical mixing; optical communications link. At the level of *Introduction to Optical Electronics* by Yariv and *Introduction to Masers and Lasers* by Seigman.

4431–4432 Electronic Circuit Design (u,g). Fall and spring. Credit three hours per term. Two lectures, one recitation, one laboratory. Prerequisite: 4322. Mr. Bryant.
Design techniques for circuits used in electronic instrumentation. Circuits will be designed to provide specific functions, then constructed and tested in the laboratory. At the level of *Pulse Digital and Switching Waveforms* by Millman and Taub.

4433 Semiconductor Electronics I (u,g). Fall. Credit four hours. Three lectures, one laboratory. Prerequisite: 4302, 4322. Mr. Ankrum.
Band theory of solids; properties of semiconductor materials; the physical theory of p-n junctions, metal-semiconductor contacts, and p-n junction devices; device fabrication; properties of semiconductor devices such as diodes and rectifiers, light-sensitive and light-emitting devices, field effect and bipolar transistors, unijunction transistors, p-n-p-n devices (diodes, controlled rectifiers, and switches), etc.; device equivalent-circuit models; field-effect and bipolar transistor-amplifier stages. At the level of *Semiconductor Electronics* by Ankrum.

4434 Semiconductor Electronics II (u,g). Spring. Credit four hours. Three lectures, one laboratory. Prerequisite: 4433. Mr. Ankrum.
A continuation of Semiconductor Electronics I with emphasis on the application of semiconductor devices as active or passive elements in circuits for use as power supplies, power controls, amplifiers, oscillators, and multivibrators, pulse circuits, gates and switches, etc.; transistor noise; integrated circuits.

[**4435 Electronics and Music (u,g).** (See section Courses of Interest to Students in Other Curricula.) Not offered in 1971–72.]

[**4436 Electronic Processing of Audio Signals (u,g).** Spring. Credit three hours. Open to graduate and upperclass undergraduate electrical engineering students for Technical Elective credit. Not offered in 1971–72.]
A technical introduction to acoustic sources, propagation media, and receptors and the problem of interfacing electronic equipment with the acoustic environment. Topics include acoustic oscillators, vibrating strings, plasma waves, spherical waves, loudspeakers, microphones, properties of large enclosures, audio amplifiers, circuits, considerations governing signal-to-noise ratio optimization, tape recorder technology, professional audio practices and circuitry, electronic musical instrument circuitry, and electronic music instrumentation. Outside work will include independent reading and the writing of several research reports.]

4437–38 Solid State Microwave Devices and Subsystems I and II (u,g). Fall and spring. Credit three hours. Two lectures, one laboratory. Prerequisite: 4302 and 4312 or equivalents. Messrs. Dalman and Lee.
A theoretical and experimental study of modern solid state microwave devices and subsystems based on the Gunn Effect diode, IMPATT diode, TRAPATT diode, tunnel diode, p-n diode, and the transistor. Initially, the basic elements of microwave systems and subsystems such as oscillators, amplifiers, modulators, and detectors are studied, and then more complex elements such as microwave network analyzers, superheterodyne receivers, spectrum analyzers, noise measuring equipment, time domain reflectometers, and experimental Doppler Radars. Typical uses of solid state devices in these subsystems are discussed and analyzed. In many cases the subsystems

themselves are used to characterize the circuit parameters of microwave solid state devices and other subsystems. As part of the course, the student will have an opportunity to study and operate a wide variety of modern test equipment such as the H.P. Network Analyzer, Sampling Oscilloscopes, near-carrier oscillator noise test sets, Spectrum Analyzers, and microwave laboratory test bench equipment. He will also participate in the design and testing of varactor tuned oscillators, low noise oscillators, Doppler Radar speed measuring devices, and other devices and subsystems of interest to the class. At the level of *Microwave Semiconductor Devices and Their Applications* by Watson.

4531 Quantum Electronics I (g). Fall. Credit four hours. Three lectures, one recitation-computing. Prerequisite: 4311, 4312, and Physics 443 or 4411. Mr. Wolga.
A detailed treatment of the physical principles underlying optical masers, related fields, and applications. Topics will include: a review of quantum mechanics and the quantum theory of angular momentum; the interaction of radiation and matter; the quantum mechanical density matrix and macroscopic material properties; theory of the laser and maser. At the level of *Quantum Electronics* by Yariv and *Fundamentals of Quantum Electronics* by Pantell and Puthoff.

4532 Quantum Electronics II (g). Spring. Credit four hours. Three lectures, one recitation-computing. Prerequisite: 4531 or consent of instructor. Mr. McFarlane.
A continuation of the treatment of the physical principles underlying optical masers and related fields. Topics will include: optical resonators; output power of amplifiers and oscillators; dispersive effects and laser oscillation spectrum; Lamb theory; spectroscopy of atoms, molecules and ions in crystals as examples of laser media; survey of chemical and dye lasers; noise in optical devices; principles of electrooptic and parametric devices.

4534 Nonlinear and Quantum Optics (g). Spring. Credit four hours. Three lectures, one recitation. Prerequisite: 4531 or Physics 572. Mr. Tang.
A detailed study of recent developments in the theory and application of nonlinear and coherent optics. Topics will include the use of density matrix and quantum field theory in nonlinear optics and the theory of coherence; spontaneous and stimulated Brillouin, parametric, and Raman processes; optical subharmonic and harmonic generation; optical mixing; frequency down- and up-conversion processes; optical parametric oscillator and other nonlinear optical devices. At the level of current published literature on these topics.

[**4535 Solid State Devices I (g).** Fall. Credit four hours. Three lectures. Prerequisite: 4412 or equivalent. Not offered in 1971–72.
A study of the properties of semiconductor devices with emphasis on low-frequency operation (below 1000 GHz). Devices based on the tunnel effect: tunnel diodes, zener diodes, field emitter cathodes, thin film resistors. Devices based on charge flow across semiconductor-semiconductor contacts: p-n diodes, avalanche diodes, transistors, field effect transistors, unipolar transistors. Devices based on metal semiconductor contacts: Schottky diode, Schottky triode. Emphasis is placed on determining the factors underlying performance capabilities. Equivalent circuits are developed. The student will either carry out a term laboratory project or prepare a term paper on an appropriate contemporary topic. The course is presented at the level of *Physics of Semiconductors* by Moll and of current papers published in the *IEEE Transactions on Electron Devices*.]

[**4536 Solid State Devices II (g).** Spring. Credit four hours. Three lectures. Prerequisite: 4551 or equivalent. Not offered in 1971–72.
A study of the properties of semiconductor devices with emphasis on high frequency operation (above 1000 GHz). The approaches to the analysis to be studied are: ballistic analysis, electronic-network analysis, space-charge wave and coupled-mode analysis. Devices studied include avalanche microwave diode (Read diode), Gunn oscillators, fast response photodiodes, and other contemporary devices. Emphasis is placed on determining the factors that underlie the performance capabilities. Equivalent circuits are developed. The student will either carry out a term laboratory project or prepare a term paper on an appropriate contemporary topic. The course is presented at the level of current papers published in the *IEEE Transactions on Electron Devices*.]

4537 Integrated Circuit Techniques (u,g). Fall. Credit four hours. Two lectures, one laboratory. Prerequisite: 4411 or equivalent. Mr. Frey.
Integrated circuit techniques applicable in the fields of computer, telecommunication, and opto-electronics are covered. The emphasis is on the device technology and the device system interface. Computer logic and memory circuits with special interest in monolithic MOS structures are discussed. Telecommunication applications concentrate on microwave hybrid integration of avalanche diode and Gunn and LSA oscillators in transmitters and receivers. In optoelectronics, solid state sensor and display panels are treated, particularly incorporating III-V and II-VI compound semiconductor devices. Each student has a term project. Relevant current publications are studied.

4631 Physics of Solid State Devices (g). Spring. Credit two or three hours. Two lectures. Prerequisite: 4536 or permission of the instructor. Mr. Lee.
The phenomena and problems associated with conduction in high electric fields will be considered; the emphasis will be mainly on semiconductors. A review will be given of hot electron phenomena, especially where instabilities arise because of multivalley band structure or other interaction of charge carriers with the host crystal. Basic theory of electron and hole scattering by phonons will be covered and methods of obtaining distribution functions from the Boltzmann equation will be examined. In addition, modifications required by complications of band structure will be discussed.

[**4632 Physics of Solid State Devices (g).** Credit two or three hours. Two lectures. Prerequisite: 4631 or permission of the instructor. Not offered in 1971–72.
The analysis of solid state devices of current interest (avalanche, LSA, Gunn devices, etc.) will be considered in sufficient detail to give an understanding of some of the limitations involved in the design of such devices. Particular scattering mechanisms and band structure complications will be considered in obtaining realistic distribution functions. Emphasis will be on analytical solutions because of the physical insight they afford, but numerical methods will also be considered. The number of devices considered will be limited, but subjects of specific interest to individuals can be considered on a seminar basis.]

Power Systems and Machinery

4441 Contemporary Electrical Machinery I (u,g). Fall. Credit three hours. Two lecture-recitations, one laboratory-computing. Prerequisite: 4302.
Emphasis on engineering principles. Real- and reactive-power requirements of core materials with symmetrical and biased magnetizing forces; analysis and characteristic prediction of high-efficiency transformers; magnetic amplifiers, energy transfers among electric circuits, magnetic fields and mechanical systems; control of magnetic field distribution by reluctance and winding distribution; travelling fields from polyphase excitation; elementary idealized commutator-type, asynchronous and synchronous machines.

4442 Contemporary Electrical Machinery II (u,g). Spring. Credit three hours. Two lecture-recitations, one laboratory-computing. Prerequisite: 4302.
Emphasis on engineering principles. Production of air-gap magnetic fields; elementary and idealized rotating machines; steady state and transient characteristics of realistic rotating machines; a-c commutator-type single-phase motors; polyphase synchronous and single-phase induction machines; recently developed types; Saturistor motor, self-excited a-c generators; miscellaneous rotary devices; Hysteresis motor, selsyns, amplidynes, frequency converters.

4443 Power System Equipment (u,g). Fall. Credit three hours. Two lectures, one computing. Prerequisite: 4302, 4942, or 342. Mr. Zimmerman.
Engineering responsibilities for system equipment and control are studied. Emphasis is placed on producer-user relations for catalog or built-to-order items. Calculations and test requirements of electrical apparatus for electrical power production, distribution, and use are considered. Prime movers, generators and their accessories, switchgear, protective devices, power transformers, converters, towers, conductors, and regulating devices are analyzed. Inspections of nearby plants and equipment supplement classroom work.

4444 High-Voltage Phenomena (u,g). Spring. Credit three hours. Prerequisite: 4302, 4942, or consent of instructor. Mr. Zimmerman.
The study of problems of the normal operations of power apparatus at very high voltages. The abnormal conditions imposed by lightning and the methods employed to assure proper operation are considered. Laboratory testing of equipment under actual or simulated conditions, being an essential step in the engineering design of high-voltage apparatus, is given particular attention. Considerable attention is given to dielectric behavior, traveling wave, and dielectric testing techniques. Electrical manufacturing test facilities are visited.

[**4445 Electric Energy Systems I (u,g).** Credit four hours. Three lecture-recitations, one computing. Prerequisite: 4322 or 4942 and consent of instructor. Not offered in 1971–72.
The physical and engineering principles underlying steady state operation and control of modern electric power systems, with emphasis on the characteristics of major power-system parameters. Theory of electromechanical energy converters, power transformers, conventional transmission lines and cables, power networks, and other power-system components; use of the digital computer as a dynamic "laboratory" model of a complex power system for load-flow studies. Laboratory-computing periods will include selected experiments with small electromechanical energy converters. At the level of *Elements of Power System Analysis* (2nd ed.) by Stevenson.]

[**4446 Electric Energy Systems II (u,g).** Credit four hours. Three lecture-recitations, one computing. Prerequisite: 4445. Not offered in 1971–72.
Continuation of principles presented in Electric Energy Systems I with emphasis on transient behavior of power networks. Theory of unbalanced systems, symmetrical components, protective relaying systems, power-system stability, high-voltage–direct-current systems and economic dispatch; use of the digital computer for fault studies and economic analysis. At the level of *Elements of Power System Analysis* (2nd ed.) by Stevenson.]

Communications, Information, and Decision Theory

4473 Coding Algorithms (u,g). Fall. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: some knowledge of linear algebra. For the laboratory, Fortran, PL-I, or Assembly language programming. Mr. Jelinek.
Coding algorithms for compression and storage of information, for correction of errors in digital data processing and transmission, and for synchronization. Design, analysis, and implementation of underlying codes. Linear block codes, convolutional codes, maximum likelihood and sequential decoding, linear sequential machines, cyclic codes, Bose-Chaudhuri codes, burst error protection, threshold decoding, variable length source coding. Laboratory consists of demonstrations and projects involving design and computer simulation, modification, and evaluation of coding algorithms covered in lecture. At the level of *An Introduction to Error Correcting Codes* by Lin.

4474 Fundamental Information Theory (u,g). Spring. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: 4401 or equivalent knowledge of probability. Prerequisite for laboratory only: 4473 with laboratory. Mr. Jelinek.
Fundamental results of information theory and their application to information storage, compression, processing, and transmission. The basis of modern design of digital communication systems. Source coding, properties of entropy, and other information measures. Signal selection and detection aspects of noisy transmission channels. Channel capacity and Shannon's coding theorems. Analysis of sequential decoding. Fidelity criteria and rate-distortion functions. Communication over Gaussian channels. Laboratory projects investigate through computer simulation the statistical problems involved with information source and channel characterization and approximation (quantization), and evaluate the advantages and limitations of the various coding algorithms introduced in 4473. At the level of *Information Theory* by Ash.

4476 Statistical Aspects of Communication (u,g). Spring. Credit four hours. Three lectures, one recitation. Prerequisite: 4401 or equivalent. Mr. McGaughan.
Analysis of analog and digital communication systems in the presence of random signals and noise. System optimization, matched filters, linear smoothing, and prediction of stationary processes. Modulation systems, performance of analog systems in time and frequency multiplex with additive noise; digital modulation systems, PCM systems with additive noise. Design of signals for digital transmission. Receiver optimization, design of decision oriented receivers,

error bounds; selected topics in hypothesis testing and parameter estimation applied to receiver design.

4672 Foundations of Inference and Decision Making (g). Spring. Credit three hours. Three lectures. Prerequisite: a course in probability and some statistics, or consent of the instructor. Mr. Fine.
Much advanced research in information processing and its applications involves sources about which we have very little knowledge and the use of performance criteria of doubtful adequacy. These difficulties motivate an examination of methods for characterizing uncertainty and chance phenomena and for transforming information into decisions and optimal systems. The discussion of the foundations of inference centers on various approaches to the interpretation and formalization of probability, including the following: axiomatic systems of comparative probability; Kolmogorov system of quantitative probability; relative frequency interpretations; computational complexity, randomness, and probability; classical probability and invariance; logical probability and induction; subjective probability and personal decision making. The discussion of the foundations of decision making will center on utility theory, axiomatic rationality, statistical decision theory, the nature of a good system, and recent work on system design when there is little prior information.

[**4673 Principles of Analog and Digital Communications (g).** Spring. Credit four hours. Three lectures. Prerequisite: 4508 or consent of instructor. Not offered in 1971–72.
The fundamentals of information theory, signal theory, and statistical estimation and decision theory are used to formulate approaches to the solution of problems arising in digital and analog communication. Particular topics are: receiver and signal design, probability of error, capacity, threshold effects for the additive Gaussian channel. Extensions to the additive Gaussian channel: feedback, random gain and phase, diversity. Time-variant Gaussian channels; receiver and signal design, probability of error, and capacity. At the level of *Principles of Coherent Communication* by Viterbi.]

[**4674 Advanced Topics in Information Theory (g).** Fall. Credit four hours. Three lectures. Prerequisite: 4474 and either 4507 or Mathematics 571, or consent of instructor. Not offered in 1971–72.
An in-depth treatment of an information theory research area. The topic varies from year to year and will be chosen from the following subjects: Source encoding (rate distortion theory), convolutional codes and sequential decoding, information nets, ergodic theory and information in abstract spaces, and complexity and instrumentability of coding schemes.]

4676 Decision and Estimation Theory for Signal Processing (g). Spring. Credit four hours. Three lectures. Prerequisite: coregistration in 4507 or Mathematics 571. Mr. Fine.
An examination of selected decision or estimation problems encountered in the design and analysis of radar/sonar target discrimination, signal demodulation, and pattern classification systems. The hypotheses of risk and uncertainty, the role of objectives, criteria for evaluating decision or estimation procedures, and characteristics of such procedures. Additional topics, drawn from the fields of parametric and nonparametric statistics, empirical time series analysis, and nonprobabilistic decision or estimation procedures, will be treated as required for the resolution of the selected problems.

Computing Systems and Control

4481–4482 Feedback Control Systems (u,g). Fall and spring. Credit three hours (four hours with laboratory). Prerequisite: 4302 or consent of instructor. Messrs. Kim and Thorp.
The analysis of feedback control systems and synthesis techniques to meet specifications or minimize performance indices. Mathematical models of physical systems and solution of differential equations by the Laplace Transform; transfer functions. The state-space approach to control systems; observability, controllability. Analysis and synthesis of linear control systems by root locus and frequency response methods. Non-linearities in control systems; analysis and compensation using describing functions and the phase plane; Lyapunov stability. Sampled-data systems and digital compensation. An introduction to parameter optimization and optimal control. Laboratory work consists of familiarization with system components and correlation of transient and frequency responses; synthesis of linear and optimal control systems and analysis of nonlinear and sampled-data systems using analog and digital computers.

[**4483 Analog Computation (u,g).** Fall. Credit four hours. Two lectures, one laboratory. Prerequisite: concurrent registration in 4401 or an equivalent background with consent of the instructor. Not offered in 1971–72.
Concepts and principles of analog computation and simulation as applied to engineering analysis and design. Linear, time-varying, and nonlinear differential equations. Automatic iterative and basic optimization techniques using digital logic. Laboratory work with general-purpose analog computers. At the level of *Methods of Solving Engineering Problems Using Analog Computers* by Levine.]

[**4484 Analog-Hybrid Computation (u,g).** Spring. Credit three or four hours by permission of instructor. Two lectures, one laboratory. Prerequisite: 4483. Not offered in 1971–72.
Theory, design, characteristics, and programming of analog-oriented hybrid computer systems; analog-digital computer linkage systems; error analysis and error compensation in hybrid computation; theory and laboratory work on automatic iterative procedures, steepest-descent programs, parameter optimization and parameter identification methods. The laboratory will make use of an analog computer linked with digital logic components. At the level of *Hybrid Computation* by Bekey and Karplus.]

4487 Switching Circuits and Logic Design (u,g). Fall. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: Mathematics 293–294 or equivalent. Mr. Torng.
Switching devices, Boolean algebra; function minimization and decomposition; adders and other combinational circuits; number representation and codes; synchronous and asynchronous sequential circuits; circuit equivalence; secondary assignments; counters and shift registers; fault detection and diagnosis. Topics for the optional laboratory session: design and construction with MSI modules of counters, shift registers, adders and other arithmetic circuits in digital computers. At the level of *Switching Circuits: Theory and Logic Design* by Torng.

4488 Structures of Computing Systems (u,g). Spring. Credit three or four hours (four hours with laboratory). Three lectures, one laboratory. Prerequisite: 4487 or Computer Science 401 or consent of the instructor. Mr. Torng.
Architecture and design of computing systems; con-

figuration of components; memory organization; central processing unit design; input-output management, channel controller; program interrupt and service interrupt; fault detection and diagnosis; systems in time-sharing environment. Topics for the optional laboratory session: design and implementation of small scale general purpose or special purpose calculators and computers.

4505 Estimation and Control in Discrete Linear Systems (g). Fall. Credit four hours. Three lectures. Prerequisite: 4401 or consent of instructor. Mr. Thorp.
Optimal control, filtering and prediction for discrete time linear systems with extensive use of the APL/360 system. Approximation on discrete point sets, curve fitting with various error measures. Modelling of discrete time systems with applications to tracking and estimation problems. Optimal control of discrete time linear systems, the principle of optimality. Optimal filtering and prediction for discrete time linear systems, Kalman filtering. Stochastic optimal control, the separation principle. No knowledge of a programming language is assumed; the APL language will be learned during the term through use of a library of programs written for the course. At the level of *Stochastic Optimal Linear Estimation and Control* by Meditch.

4506 Optimal Control and Estimation for Continuous Systems (g). Spring. Credit four hours. Three lectures. Prerequisite: 4505 or consent of instructor. Mr. Thorp.
Methods of design problem formulation, computational techniques, and mathematical background are developed for the implementation of continuous optimal control and estimation. Deterministic and stochastic controls as well as unbiased estimators are formulated on both finite and infinite time intervals. Extensive examples are given such as re-entry vehicle flight-control, rocket-booster guidance, aircraft tracking, and human operator simulation. Methods of successive approximation and substitution are presented for minimization with respect to parameters and functions, with and without equality and inequality constraints. Properties of Lyapunov and Riccati equations are discussed. Material is illustrated by the student use of an APL library of computer programs for the automated design of continuous controls and estimators.

[**4580 Machine Organization (u,g).** Spring. Credit three hours. Three lectures. Prerequisite: some knowledge of computers and their use. Not offered in 1971–72.
Design and analysis of computer systems from the viewpoint of systems engineers. Both conventional and unconventional computer systems will be treated. Emphasis will be on the modelling and evaluation of large computer systems. Topics will include machine modules, communication between modules, states of modules and the concepts of interrupts, storage allocation, processor allocation, statistical and algebraic models for computer systems and information processing systems, simulation languages, simulation models and system evaluation, teleprocessing systems, failure-tolerant computer systems, and parallel processing systems.]

[**4681 Random Processes in Control Systems (g).** Spring. Credit four hours. Three lectures. Prerequisite: 4508 and 4506. Not offered in 1971–72.
Prediction and filtering in control systems; Gaussian-Markov sequence, Gaussian-Markov process, prediction problem, generalized Wiener filtering, stochastic optimal and adaptive control problems. Selected topics: Bayes decision rule, min-max policy, maximum likelihood estimate, control of systems with uncertain statistical parameters; stochastic differential equations, optimal nonlinear filtering; stability of control systems with random parameters.]

Radio and Plasma Physics and Electromagnetic Theory

[**4461 Wave Phenomena in the Atmosphere (u,g).** Fall. Credit three hours. Three lecture-recitations. Prerequisite: 4302, 4312. Not offered in 1971–72.
An elementary treatment of wave phenomena in the atmosphere of the earth, including gravity waves, planetary waves, acoustic waves, radio waves, and plasma waves; attention is directed to the role of these phenomena in various atmospheric processes and engineering problems such as weather, pollution, radio communication, atomic fall-out.]

[**4462 Radio Engineering (u,g).** Spring. Credit three hours. Three lecture-recitations. Prerequisite: 4312, 4401. Not offered in 1971–72.
A study of electrical systems for communications, control, detection, and other purposes in which radiowaves play a central role: system functions, including generation, modulation, transmission, reception, and demodulation; guidance, radiation, and propagation of radiowaves, including transmission lines and waveguides, antenna systems, and the effects of atmospheric inhomogeneity; system design problems.]

4464 Elementary Plasma Physics and Gas Discharges (u,g). Spring. Credit three hours. Two lectures, one laboratory. Prerequisite: 4312 or equivalent. Messrs. Nation and Wharton.
Review of electromagnetic wave theory and applications. Gas discharges and arcs: positive column, collisions, mobility, diffusion, breakdown, sheaths, DC and RF excitation, transition from glow to arc, Langmuir and conductance probes, reflex discharge, effects of magnetic field. Plasma as a dielectric medium, interaction of electromagnetic waves (e.g., microwaves) with plasma in free space and finite regions. Plasma oscillations, space-charge waves, cyclotron harmonic radiation, Tonks-Dattner resonances, effects of plasma temperature. At the level of *Plasma Diagnostics with Microwaves* by Heald and Wharton.

4511 Electrodynamics (g). Fall. Credit four hours. Three lectures, one recitation. Prerequisite: 4302, 4312, or equivalent. Mr. McIsaac.
Foundations of electromagnetic theory. Maxwell's equations, electromagnetic potentials, and integral representations of the electromagnetic field. Special theory of relativity. Radiation of accelerated charges and Cerenkov radiation. Electrodynamics of dispersive and anisotropic media. Normal modes of waveguides and cavities. Surface waves and leaky waves. At the level of *Theory of Electromagnetism* by Jones.

4514 Microwave Theory (g). Spring. Credit four hours. Three lectures, one recitation. Prerequisite: 4302, 4312, or equivalent. Mr. McIsaac.
Theory of passive microwave devices. Waves in homogeneous and inhomogeneous waveguides; propagation and distortion of pulses; application of gyrotropic media to nonreciprocal waveguide devices. Scattering matrix analysis of multiport junctions, resonant cavities, directional couplers, isolators, circulators. Periodic waveguides. Elastic waves in solids and their microwave applications. At the level of *Introduction to the Theory of Microwave Circuits* by Kurokawa.

4551–4552 Upper Atmosphere Physics I and II (u,g). Fall and spring. Credit three hours each term. Three lectures. Prerequisite: 4312 or equivalent. Messrs. Farley and Brice.
The physical processes governing the behavior of the earth's ionosphere and magnetosphere. Topics will include diagnostic measurement techniques; production, loss, and transport of charged particles in the ionosphere and magnetosphere; temperature variations; airglow; tidal motions, winds, and gravity waves in the ionosphere; the electrical conductivity of the ionosphere, the dynamo-current system, and the equatorial and auroral electrojets; plasma instabilities in the ionosphere; interactions between the ionosphere, magnetosphere, and solar wind; acceleration and drift of energetic particles in the magnetosphere; precipitation of particles and the aurora; magnetic and ionospheric storms. At the level of *Introduction to Ionospheric Physics* by Rishbeth and Garriott.

4561 Introduction to Plasma Physics (u,g). Fall. Credit three hours. Three lectures. Prerequisite: 4311, 4312 or equivalent. Open to fourth-year students at discretion of instructor. Mr. Sudan.
Plasma state; motion of charged particles in fields; adiabatic invariants, collisions, coulomb scattering; Langevin equation; transport coefficients, ambipolar diffusion, plasma oscillations and waves; hydromagnetic equations; plasma confinement, energy principles, and microscopic instabilities; test particle in a plasma; elementary applications. At the level of *Elementary Plasma Physics* by Longmire.

4564 Advanced Plasma Physics (u,g). Spring. Credit three hours. Three lectures. Prerequisite, 4561. Mr. Sudan.
Boltzmann and Vlasov equations; moments of kinetic equation, Chew-Goldberger-Low theory, waves in hot plasmas, Landau damping, instabilities due to anisotropies in velocity space, gradients in magnetic field, temperature and density, effects of collisions and Fokker-Planck terms; high-frequency conductivity and fluctuations, quasi-linear theory; nonlinear wave interaction, weak turbulence and turbulent diffusion.

[**4565 Radiowave Propagation I (u,g).** Fall. Credit three hours. Three lectures. Prerequisite: 4312 and 4401 or equivalent. Not offered in 1971–72.
Propagation in the earth's environment: the troposphere, ionosphere, magnetosphere, and interplanetary space. Diffraction and surface wave propagation; tropospheric refraction and ducting; propagation in the ionospheric plasma, including magnetoionic theory, the CMA diagram, cross modulation and Faraday rotation, whistler mode propagation, ion effects and ion whistlers, group velocity and ray tracing. WKB solutions of the coupled-wave equations.]

[**4566 Radiowave Propagation II (u,g).** Spring. Credit three hours. Three lectures. Prerequisite: 4565 or equivalent. Not offered in 1971–72.
Full-wave solutions of the coupled-wave equations; interactions between particles and waves in the magnetosphere; radar astronomy; the scattering of radio waves from random fluctuations in refractive index; tropospheric and D region ionospheric scatter propagation; incoherent scatter from the ionosphere and its use as a diagnostic tool; radio star and satellite scintillations and their use in studying the ionosphere and solar wind.]

4567 Antennas and Radiation (u,g). Spring. Credit three or four hours (four hours with laboratory). Three lectures. Prerequisite: 4312, 4401, or equivalent.
Formulation of the electromagnetic field in terms of vector and scalar potentials; radiation from elemental electric and magnetic dipoles. Linear radiators; radiation from short dipoles, small loops; resonant wire antennas; long wire antennas, linear arrays, and pattern synthesis; impedance properties of wire antennas, including mutual impedance, parasitic elements; wire receiving antennas. Aperture antennas: uniqueness theorem for vector fields, equivalence and induction principles; radiation from open-ended waveguides, horn antennas, reflector antennas; Babinet's principle; slot antennas. Laboratory experiments will be conducted on an antenna range. At the level of *Electromagnetic Waves and Radiating Systems* by Jordan.

[**4661 Kinetic Equations (g).** (Same as Applied and Engineering Physics 8261.) Spring. Credit three hours. Three lectures. Prerequisite: Physics 561, 562, or permission of instructor. Not offered in 1971–72.
Designed for students wishing a firm foundation in fluid dynamics, plasma-kinetic theory, and nonequilibrium statistical mechanics. Brief review of classic dynamics. The concept of the ensemble and the theory of the Liouville equation. Prigogine and Bogoliubov analysis of the BBKGY sequence. Chapman-Kolmogorov analysis of Markovian kinetic equations. Derivation of fluid dynamics. Kinetic formulation of the stress tensor. Boltzmann, Krook, Fokker-Planck, Landau, and Balescu-Lenard equations. Properties and theory of the Linear Boltzmann collision operator. Chapman-Enskog and Grad methods of solution of the Boltzmann equation. Klimontovich formulation. Coarse graining and ergodic theory. At the level of *Introduction to the Theory of Kinetic Equations* by Liboff.]

General

4591–4592 Project (u,g). Fall and spring. Credit three hours.
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 his project; an engineering report on the project is required.

4595–4596 Electrical Engineering Design (g). Fall and spring. Credit three hours per term. Offered for students enrolled in the M.Eng. (Electrical) program. Utilizes real engineering situations to present fundamentals of engineering design.

4691–4692 Electrical Engineering Colloquium (g). Fall and spring. Credit one hour per term. For graduate students enrolled in the Field of Electrical Engineering. Messrs. Frey and Ku.
Lectures by visiting authorities, staff, and graduate students. A weekly meeting for the presentation and discussion of important current topics in the field.

4700–4800 Special Topics in Electrical Engineering (g). Credit one to three hours.
Seminar, reading course, or other special arrangement agreed upon between the students and faculty members concerned.

Courses of Interest to Students in Other Curricula

4110 Computer Appreciation (u). Either term. Credit three hours. Two lectures, one laboratory.
Organization and structure of the digital computer with particular reference to the contribution of modern technology to computer development. The digital computer will be separated into its basic units and

the function of these units alone and in total will be investigated. Tools employed in this investigation will be a mechanical simulator of a digital computer (Digi-Comp II) and a logic board consisting of switches and relays. Work with machine language and the development of "software" will lead into programming languages and their application. Without emphasizing program techniques, the course should, nevertheless, provide a cure for "digi-comphobia" (the irrational fear of digital computers). No technical background beyond high school mathematics is required. At the level of *The Man-Made World* by the Engineering Concepts Curriculum Project Committee.

4210 Introduction to Electrical Systems (u). Either term. Credit three hours. Three lecture-recitations. Prerequisite: Mathematics 192 and Physics 112. Mr. McIsaac and staff.
A core-science course intended to develop competence in several analysis skills appropriate to the field of electrical engineering and to impart understanding of the physical basis for the concepts associated with the skills. Topics include: electrical circuit elements (resistors, capacitors, inductors, independent sources, and branch relationships); time functions and their representation (real exponentials, complex numbers, trigonometric functions, and complex exponentials); response of simple networks and the impedance concept (natural response, forced response to periodic excitation, and pole-zero concepts); circuit equations and methods of solution (branch equations, Kirchhoff's laws, nodal and mesh equations, matrix methods of solution, and Norton and Thevenin equivalents); controlled sources and modelling of devices (representation of idealized electronic and electromechanical devices).

[**4435 Electronics and Music (u,g).** Fall. Credit three hours. Electrical engineering students may take the course as a free elective. Not offered in 1971–72.
An introduction to musical acoustics and the application of electronics to production as well as reproduction of musical material. Topics include physical properties of sound, historical development of musical materials, physical properties of musical instruments, speech and hearing mechanisms, electronic terms and concepts, elements of sound reproducing chains, home and professional audio practices, electronic musical instruments, and electronic music composition processes. Outside work will include independent reading and writing of papers on selected topics.]

4436 Electronic Processing of Audio Signals (u,g). (See section Electronics.)

4921–4922 Electrical Engineering Laboratory (u). Fall and spring. Credit one hour each term. One laboratory.
An introduction to electrical and electronic instrumentation, high-vacuum and solid state devices, and analog computation.

4940 Introductory Electrical Engineering (u). Fall and spring. Credit three hours. Two lectures, one recitation-computing. Prerequisite: Physics 112, Mathematics 294, and Physics 213. Mr. Osborn.
The major topic areas of circuits, electronics, and electromechanics are treated by examining the principal devices encountered in each area and considering their application. Although emphasis is placed on practical aspects, a unified treatment of devices and circuits is developed which can be applied to topics beyond the scope of the sequence. The student is expected to acquire an accurate, working knowledge of the principles, materials, and devices commonly used by electrical engineers. Some specific devices considered are transformers, tubes, transistors, motors, and generators. At the level of *Basic Electrical Engineering* by Fitzgerald, Higginbotham, and Grabel.

Engineering Physics

See p. 57.

Environmental Engineering

See p. 63.

Geological Sciences

The courses in Geological Sciences are listed under the following headings: *General Geology (Principles and Processes, Physical Processes), Physical Geography, Geochemistry (Mineral Materials and Processes, Mineral Deposits), Geophysics, Applied Geological Science, Geobiology (Paleontology and Stratigraphy),* and *Seminars and Special Work.*

Physical Geography

111 Earth Science (u). Fall. Credit three hours (see Earth Science Laboratory 113). Combine with Geography 212 for a survey of physical geography. Lectures, M W F 9:05. Mr. Bloom.
Physical geography, including the spatial relationships of the earth, moon, and sun that determine the figure of the earth, time, seasons, atmospheric and oceanic circulation, and climates.

113 Earth Science Laboratory (u). Fall. Credit one hour. To be taken concurrently with Earth Science 111. Laboratory, W or Th 2–4:25. Mr. Bloom.
Observation and calculation of daily, monthly, and seasonal celestial events; topographical mapping and map interpretation; world climatic regions.

212 Mineral Resources (u). Spring. Credit three hours. Lectures, M W F 9:05. Staff.
Utilization of and our dependence upon mineral resources; their nature, occurrence, distribution, and availability at home and abroad. Political and economic aspects of their availability and control.

610 Special Work (g). Throughout the year. Credit two hours a term. Prerequisite: consent of the instructor. Staff.
Special or original investigations in physical geography on the graduate level.

General Geology

Principles and Processes

101 Introductory Geological Science (u). Fall. Credit three hours. Lectures, T Th 11:15. Two scheduled preliminary examinations will be held at 7:30 p.m. during the term. Laboratory, M T W Th or F 2–4:25, S 10:10–12:35. Field trips. Staff.
Designed to give students a comprehensive understanding of the earth processes, features, and history. Provides the basic knowledge necessary for more specialized courses or a major in geological sciences. Study of the earth, particularly materials, structure, internal condition, and the physical and

chemical processes at work. Principles of interpretation of earth history, evolution of continents, oceans, mountain systems, and other features; development of its animal and plant inhabitants.

102 Introductory Geological Science (u). Spring. Credit three hours. Prerequisite: 101. Lectures, T Th 11:15. Two scheduled preliminary examinations will be held at 7:30 p.m. during the term. Laboratory, M T W Th or F 2–4:25, S 10:10–12:35. Field trips. Staff.
A continuation of Geology 101.

202 Ancient Life (u). Spring. Credit three hours. No prerequisite, but 102 is desirable. Lectures, M W F 11:15. Mr. Wells.
A cultural course devoted to a review of the fossil remains of life in the geologic past as the main basis of the concept of organic evolution. Vertebrate forms from fish to man are stressed.

203 Geology and the Environment (u). Fall. Credit three hours. Lectures, T Th 9:05. Laboratory, T W or Th 1:25–4:25. Two scheduled preliminary examinations will be held at 7:30 p.m. during the term and a laboratory examination will be held at 7:30 p.m. the last week of the term. Field trips. Mr. Kiersch.
The principles of geological science with emphasis on the physical phenomena and rock properties as they influence the natural environments of man. The cause and effect of geological problems encountered in the planning, construction, and operation of man's works are analyzed in the laboratory along with the influence of environmental factors.

Physical Processes

322 Structural Geology—Tectonics (u,g). Spring. Credit four hours. Prerequisite: 102 or 203, and 351; 352 recommended. Lectures, M W 11:15. Laboratory, M 2–4:25, and additional assigned problems. Field trips. Mr. Kiersch.
Nature, origin, and recognition of geologic structures. Behavior of geologic materials, stresses, geomechanical and tectonic principles applied to the solution of geologic problems. Analysis of structural features by three-dimensional methods.

421 Sedimentation (u,g). Fall. Credit four hours. Given in alternate years. Prerequisite: 352; 441 recommended. Lectures, M W 9:05. Laboratory, T 2–4:25, and additional laboratory work. Field trips. Staff.
Source materials, mechanics of transport and dispersal, depositional environments, lithification and diagenesis of sediments. Analysis of common problems in applied fields due to these phenomena.

441 Geomorphology (u,g). Fall. Credit four hours. Prerequisite: 102. Lectures, T Th 9:05. Laboratory, T 2–4:25, and additional assigned problems. Mr. Bloom.
Description and interpretation of land forms in terms of structure, process, and stage.

444 Geological Oceanography (u,g). Spring. Credit three hours. Prerequisite: 102 or Biological Sciences 461. Lectures, M W F 9:05. Field trips. Mr. Bloom.
Shoreline erosion, transportation, and deposition; origin and structure of continental shelves and ocean basins. Geologic processes and geomorphic development in the marine environment.

542 Glacial and Pleistocene Geology (u,g). Spring. Credit three hours. Prerequisite: 441 or consent of the instructor. Lectures, T Th 9:05. Laboratory, T 2–4:25. Several Saturday field trips. Mr. Bloom.
Glacial processes and deposits and the stratigraphy of the Pleistocene.

Geochemistry

Mineral Materials and Processes

351 Mineralogy (u,g). Fall. Credit four hours. Prerequisite: 102 and Chemistry 108. Lecture, M 10:10. Laboratory, W F 2–4:25, and additional assigned problems. Staff.
Crystallography, crystal chemistry, and systematic mineralogy of the ore and rock-forming minerals.

352 Petrology (u,g). Spring. Credit four hours. Prerequisite: 351. Lectures, M F 10:10. Laboratory, Th 2–4:25 and additional assigned problems. Staff.
Composition, classification, and origin of igneous, sedimentary, and metamorphic rocks.

451 Optical Mineralogy (u,g). Fall. Credit four hours. Prerequisite: 351. Lecture, T Th 11:15. Laboratory, F S 9:05–12:20, and additional assigned problems. Staff.
Optical properties of crystals and their application to the determination and study of common rock-forming minerals with the petrographic microscope.

452 Optical Petrography (u,g). Spring. Credit four hours. Prerequisite: 352 and 451. Lecture, T Th 11:15. Laboratory, F S 9:05–12:20, and additional assigned problems. Staff.
Description, classification, and determination of the origin of igneous, metamorphic, and sedimentary rocks by the use of petrographic microscope.

551 Geochemistry (g). Fall. Credit three hours. Prerequisite: 352. Lectures, M W F 8. Staff.
Distribution of major and minor elements in the earth, geochemical cycles of the elements, and chemistry of weathering and petrogenesis.

554 X-ray Analysis (g). Spring. Credit two hours. Prerequisite: 352 or consent of the instructor. Lecture, W 12:20. Laboratory, F 2–4:25. Staff.
Theory and use of x-ray diffraction and spectroscopy in identification and analysis of minerals, rocks, and soils.

653 Advanced Petrology (g). Spring. Credit three hours. Given in alternate years. Prerequisite: 452. Lectures, T Th 9:05. Laboratory, Th 2–4:25. Staff.
Readings and discussions on the petrogenesis of igneous rocks. Laboratory studies of selected igneous rock soils.

656 Advanced Mineralogy (g). Fall. Credit three hours. Prerequisite: 452 and 554. Lectures, T Th 10:10. Laboratory, W 2–4:25. Staff.
A theoretical treatment of the crystal chemistry and thermodynamics of rock-forming minerals.

Mineral Deposits

461 Mineral Deposits: Metals (u,g). Fall. Credit four hours. Prerequisite: 352. Lectures, M W F 10:10. Laboratory, F 2–4:25. Field trips. Staff.
Principles and processes involved in the formation of mineral deposits. Modes of occurrence, origin, distribution, and utilization of the major, rare, and minor metals.

462 Mineral Deposits: Nonmetals (u,g). Spring. Credit four hours. Prerequisite: 461 or consent of the instructor. Lectures, M W F 10:10. Laboratory, F 2–4:25. Field trips. Staff.
Properties, occurrence, associations, distribution, and economic utilization of the industrial minerals and rocks.

563 Ore Microscopy (g). Fall. Credit two hours. Given in alternate years. Prerequisites: 451, 461. Laboratory, F S 7:30–9:55 a.m. Staff.

Identification of ore-minerals in polished sections which reflect light by etching and microchemical reactions: study and interpretation of mineral relationships.

Geophysics

581 Exploration Geophysics (g). Fall. Credit three hours. Given in alternate years. Prerequisite: 102 or 203, Physics 208; 322 recommended. Lectures, T Th 9:05. Laboratory, S 10:10–12:35. Assigned problems. Staff.
Elementary theory and interpretation of data from exploration geophysical methods. Environmental geology and selection of techniques for important applied areas.

583 Physics of the Earth (g). Fall. Credit three hours. Prerequisite: 322, Mathematics 112, Physics 208. Lectures and laboratory to be arranged. Staff.
Theory and field measurements of the earth's gravitational, magnetic, seismic, electrical, thermal, and radioactive properties.

584 Seismology (g). Spring. Credit three hours. Prerequisite: 583. Lectures and laboratory to be arranged. Staff.
Theory of stress and strain, seismic wave propagation, earthquake studies, and observational seismology.

586 Seminar in Rock Deformation: Geomechanics (g). Spring. Credit two hours. Prerequisites: 533 and 583. Hours to be arranged. Staff.
Review of stress analysis and behavior of materials, both the rock mass and sample. Fundamentals of deformation pertaining to the crustal rocks and the problems of applied geological science.

Applied Geological Science

532 Hydrogeology (g). Spring. Credit three hours. Given in alternate years. Prerequisites: 322 and 352; 441 recommended. Lectures, M W 9:05. Laboratory, T 2–4:25. Field trips. Staff.
Hydrologic cycle and water provinces; occurrence, movement, quantity, and chemical quality of groundwater in porous media. Water resources development.

533 Engineering Geology: Theory and Environments (g). Fall. Credit three hours. Given in alternate years. Prerequisite: 322 and 352; 441 recommended. Lectures, M W 11:15. Laboratory, M 2–4:25. Field trips. Mr. Kiersch.
Advanced study of the physical phenomena and rock properties of special importance from the planning through the operation stages of engineering works; includes underground fluids, subsidence, gravity movement, seismicity, geomechanics and stresses, rock mechanics, weathering, and geologic materials of construction. Analysis of geologic problems encountered in practice; predicting the influence of natural and man-made environmental factors.

535 Engineering Geology: Practice (g). Fall. Credit three hours. Given in alternate years. Prerequisite: 533 or 322–352 and 441. Lectures, M W 9:05. Laboratory, T 2–4:25. Field trips. Mr. Kiersch.
Application of geological principles in the planning-design, construction, and operation of engineering works. Case histories, analysis, and evaluation of physical environmental factors, remedial treatment, and reports.

561 Fundamentals of Mining Geology (g). Fall. Credit three hours. Given in alternate years. Prerequisite: 461 and 462. Lectures, M W F 10:10. Assigned problems. Field trips. Staff.
Principles of geological, geophysical, and geochemical techniques used in mineral exploration. Mining geology, guides to ore, mining methods.

562 Economics of Mineral Deposits (g). Spring. Credit three hours. Given in alternate years. Prerequisite: 461 and 462; 561 recommended. Lectures, M W F 10:10. Assigned problems. Staff.
Sampling and ore estimation. Cutoff, grade, tonnage, and economic factors related to mining and mineral marketing. Financial calculations and procedures used in mineral property valuation.

[582 **Exploration Geology (g).** Spring. Credit three hours. Recommended for all graduate students in geological sciences. Prerequisite: graduate standing and field geology. Staff. Not offered in 1971–72.
Methods of exploration and appraisal of geologic data from both field and laboratory investigations. Assessment of environmental geology and the presentation of direct and indirect information for professional purposes and applied fields.]

Geobiology

Paleontology and Stratigraphy

471 Invertebrate Paleontology (u,g). Fall. Credit four hours. For those interested in fossil evidence of the development of organisms. Prerequisite: 102; invertebrate zoology recommended. Lectures, T Th 10:10. Laboratory, W Th 2–4:25. Mr. Wells.
Paleobiology and classification of important fossil invertebrates.

472 Principles of Historic Geology (u,g). Spring. Credit four hours. Prerequisite: 322 and 471. Lectures, T Th 10:10. Laboratory, W Th 2–4:25. Mr. Wells.
Application of geologic principles to interpretation of earth history: development of the geologic column; geochronology and geochronometry; correlation and the zone concept; sedimentary environments and provinces; geosynclines and platforms; problems of the Pre-Cambrian and continental evolution.

571 Stratigraphy: Paleozoic (g). Fall. Credit three hours. Given in alternate years. Prerequisite: 472. Lectures, T Th 9:05 and W 7:30 p.m. Mr. Wells.
Principles of stratigraphy developed by detailed study of selected American and European systemic examples.

572 Stratigraphy: Mesozoic and Cenozoic (g). Spring. Credit three hours. Prerequisite: 472. T W Th 9:05. Mr. Wells.
Principles of stratigraphy developed by detailed study of selected American and European systemic examples.

672 Stratigraphy of New York State (g). Spring. Credit three hours. Given in alternate years. Prerequisite: 571. Lectures, T Th 12:20 early in the term, followed by all-day and weekend field trips. Mr. Wells.
The classic Paleozoic sections of New York studied through lectures, readings, and field observation.

Seminars and Special Work

490 Senior Thesis (u). Either term. Credit one hour. Staff.

673 Seminar in the History of Geology (g). Fall. Credit two hours. Hours to be arranged. Mr. Wells.

Seminar in Geological Sciences (u,g). Each term. No credit. For majors and required of graduate students, but open to all who are interested. T 4:45. Staff and visiting lecturers.
Reports and discussion of current research in the geological sciences.

690 Special Work (g). Throughout the year. Credit two hours per term. Prerequisite: consent of the instructor. Staff.
Advanced work on original investigations in geological sciences.

690-a Analytical geochemistry, crystallography, and mineralogy. Staff.

690-b Petrology and geochemistry of metamorphic and igneous rocks, associated metallic minerals. Staff.

690-c Coastal geomorphology and Pleistocene geology. Mr. Bloom.

690-d Engineering geology, geomechanics, and hydrogeology. Mr. Kiersch.

690-e Seismology, crustal and marine geophysics, heat flow. Staff.

690-f Invertebrate paleontology and paleoecology. Mr. Wells.

690-g Sedimentology and primary structures. Staff.

690-h Physical and engineering geology, water resources. Staff.

690-i Mineral deposits and resources, exploration geophysics. Staff.

Industrial Engineering and Operations Research

Service Courses

9114 Consumer Products Engineering (g). (Same as Chemical Engineering 5790). Fall. Credit three hours. Two lectures, one computing session. Open to qualified seniors and graduate students in the M. Eng. program. Mr. Hedrick and staff.
The organization and the interrelated departmental functions for the development of new consumer products. Case studies are drawn from the food industry to describe the special problems and situations encountered. The role of scientists and engineers in the consumer products industries is stressed. Staff will be from industry.

9135 Introduction to Game Theory (u). Spring. Credit three hours. Three lecture-recitations. Mr. Lucas.
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.

9160 Introductory Engineering Probability (u). Both terms. Credit three hours. Three lectures. Prerequisite: first year calculus. Messrs. Billera, Emmons, and Weiss.
At the end of this course a student should have a working knowledge of some of the basic tools in probability theory and their use in engineering. This course may be the last one in probability for some students, or it may be followed by a course in probability or statistics. The topics include: a definition of probability; basic rules for calculating with probabilities when the number of possible outcomes is finite; discrete and continuous random variables; probability distribution and density functions; expected values, jointly distributed random variables, and marginal and conditional distributions; special distributions important in engineering work: the normal, exponential, binomial, Poisson, and other distributions, and how they arise in practice; and Markov chains and applications.

9170 Basic Engineering Statistics (u). Both terms. Credit three hours. Two lectures, one recitation. Prerequisite: first year calculus. Messrs. Taylor and Brown.
At the end of this course a student should command a working knowledge of basic statistics as it applies to engineering work. For many students this will be the only course in statistics they will ever take. For students who wish to learn more about statistics, a course in probablity (e.g., 9460) is recommended. The topics are: graphical and numerical methods of representing data—histograms and cumulative frequency polygons, sample means and variances; basic tools of probability, discrete and continuous random variables, probability distribution and density functions, expected values and "population" moments, special distributions—the normal, chi-square, binomial and others; tests of "significance" and one- and two-sided hypothesis tests concerning the mean of a normal distribution when the standard deviation is known (unknown); hypothesis tests concerning the variance of a normal distribution; point- and confidence-interval estimation; correlation and curve fitting by least squares.

Required Courses

9310 Industrial Systems Analysis (u). Fall. Credit four hours. Three lectures, one computing session. Prerequisite: 9350 and 9370 or equivalent. Mr. Goode.
Selected methods of industrial systems analysis such as those needed in problem definition, evaluation, systems design and control, and operational decision making. Emphasis will be on the application of probability, statistics, and cost theory to typical problem situations. Network problems, reliability, and replacement situations will be discussed.

9311 Industrial Systems Design (u). Spring. Credit four hours. Two lectures, one computing session. Prerequisite: 9310. Mr. Saunders.
The design of complex man-machine systems and the methods and procedures required for their operational control. Measures of system feasibility, effectiveness, and sensitivity will be discussed and problems of system experimentation will be introduced. Much of the work of the course will be done through specific design problems.

9320 Deterministic Models in Industrial Engineering and Operations Research (u). Fall. Credit four hours. Three lectures, one recitation. Mr. Eisner.
Analysis of design, planning, and operational problems using mathematical models in which uncertainty does not play a major role. Most of the models treated are of the constrained optimization type, in which scarce resources are to be allocated among competing activities so as to maximize benefit or minimize cost; i.e., linear, nonlinear, and integer programming. Such models will be shown to arise in both industrial and nonindustrial settings; e.g., production planning, distribution, systems design,

facility location, etc. At the end of this course, the student should have facility in formulating algebraic representations of real systems; an understanding of the properties (and limitations) of specific models; and familiarity with computational methods such as the Simplex method and an understanding of why they work.

9350 Cost Accounting, Analysis, and Control (u). Either term. Credit four hours. Three lecture-recitations, one computing session. Mr. Allen.
Accounting theory and procedures, financial reports; product costing in job-order and process-cost systems—historical and standard costs; cost characteristics and concepts for analysis, control, and decision making; differences between accounting and engineering objectives in the development and uses of cost data. Capital budgeting, investment planning, and introduction to decision making based on economic criteria.

9361 Probabilistic Models in Industrial Engineering and Operations Research (u,g). Spring. Credit four hours. Three recitations, one computing session. Prerequisite: 9160 or equivalent. Mr. Emmons.
Basic probabilistic techniques will be developed and applied in engineering problem areas. Topics to be covered include: transform methods (particularly the z-transform and the Laplace transform); the Poisson process with extensions; the general birth-death process; a variety of queuing and inventory models. Theoretical background and derivations will be included to make clear the assumptions and limitations of the models and to introduce the student to the problems of formulation of analogous models found in engineering and operational situations.

9370 Introduction to Statistical Theory with Engineering Applications (u). Spring. Credit four hours. Three lectures, one recitation. Prerequisite: a course in probability (e.g., 9160). Mr. Weiss.
The course provides a working knowledge of basic statistics as it is most often applied in engineering work, and a basis in statistical theory for continued study and further application. A variety of statistical procedures are presented, together with the theoretical principles on which they are based. This course may be followed by 9512 or 9570 or by Industrial and Labor Relations 311 or Statistics and Biometry 511. Topics include a review of distributions of special interest in statistics: normal, chi-square, binomial, Poisson, t and F; introduction to statistical decision theory and Bayes procedures; basic principles underlying hypothesis tests: the Neyman-Pearson theory; one- and two-sided hypothesis tests of the mean of a normal distribution when the standard deviation is known (unknown); hypothesis tests concerning the variance of a normal distribution; basic principles of point and confidence interval estimation: minimum variance unbiased estimators, maximum likelihood estimation; confidence-interval estimates of the mean and variance of a normal distribution; the bivariate normal distribution and correlation; linear regression and curve fitting by least squares.

9383 Applications of Computer Science in Industrial Engineering and Operations Research (u,g). Spring. Credit four hours. Two lectures, one computing session. Prerequisite: Computer Science 202. Staff.
The application of computers in the analysis of industrial engineering and operations research problems. Simulation methodology. Design of data processing systems for operational control. Use of statistical and mathematical programming packages.

Graduate Courses and Honors Sections of Undergraduate Courses

Registration in the following courses will be by permission of the instructor or department head only. Registrants will be limited to those undergraduates enrolled in an Honors program or to graduate students taking a major, a minor, or an advanced professional degree in the graduate Field of Operations Research. Other qualified students will be admitted only if section sizes permit.

9460 Introduction to Probability Theory with Engineering Applications (u,g). Fall. Credit four hours. Three lectures, one recitation. Mr. Prabhu.
Covers the same topics as 9160, but all lectures and computing sessions are independent of those for 9160.

9470 Introduction to Statistical Theory with Engineering Applications (u,g). Spring. Credit four hours. Three lectures, one recitation. Prerequisite: 9160 or 9460. Mr. Brown.
Covers the same topics as 9370, but all lectures and computing sessions are independent of those for 9370.

9512 Statistical Methods in Quality and Reliability Control (u,g). Spring. Credit three hours. Three lectures. Prerequisite: 9370 or equivalent. Mr. Goode.
Control concepts: control chart methods for attributes and variables; process capability analysis; attributes acceptance sampling plans and procedures; double and multiple sampling plans; elementary procedures for variables; acceptance-rectification procedures; basic reliability concepts; exponential and normal distributions as models for reliability applications; life and reliability analysis of components; analysis of series and parallel systems; stand-by and redundancy; elementary sampling-inspection procedures used for life and reliability.

[**9513 Systems Engineering (g).** Spring. Credit three hours. Two recitations, one laboratory. Elective for graduate students and qualified undergraduates. Prerequisite: 9320 and 9370, or consent of instructor. Not offered in 1971–72.
Methods of describing, analyzing, and manipulating complex, interrelated open systems. Graphical and mathematical analysis. Techniques of design of transportation, service, and information systems and appropriate evaluation methods.]

9521 Production Planning and Control (g). Spring. Credit four hours. Three lectures. Prerequisite: 9320 and 9361 or consent of instructor. Mr. Maxwell.
Methods for the planning and control of large-scale operations with emphasis on manufacturing systems. Among the areas covered will be sales and production forecasting; manufacturing planning; routing, scheduling, and loading; sequencing; dispatching; planning and control of inventories. Emphasis will be on mathematical, statistical, and computer methods for performing these functions. The empirical systems and procedures in use will also be discussed and evaluated.

9522 Operations Research I (g). Fall. Credit three hours. Threee lecture-recitations. Prerequisite: consent of instructor. Not open to students who have had 9320. Mr. Billera.
Model design, methodology of operations research, linear programming, transportation problem, assignment problem, dual theorem, parametric linear programming, integer programming, nonlinear program-

ming, dynamic programming, introduction to inventory theory; game theory, comprehensive problems, and case studies.

9523 Operations Research II (g). Spring. Credit three hours. Three lecture-recitations. Prerequisite: 9160, 9170, or permission of the instructor. Not open to students who have had 9526. Staff.
Models for inventory and production control. Replacement theory; queuing, including standard birth and death process model and nonstandard models; application of queuing theory. Simulation. Illustrative examples and problems.

9525 Scheduling Theory (g). Fall. Credit three hours. Three lecture-recitations. Prerequisite: consent of instructor. Mr. Maxwell.
Scheduling problems; problem definition and performance measures. Single resource scheduling. MxN scheduling problems. Priority queuing approaches. Simulation of job-shop dispatching and heuristic procedures.

9526 Mathematical Models—Development and Application (g). Fall. Credit four hours. Three lecture-recitations, one computing session. Prerequisite: 9320 and 9361, or equivalent. Mr. Emmons.
Examination of probabilistic and deterministic models in relation to industrial engineering work. The function of models and their usefulness in analysis, synthesis, and design. Emphasis will be given to the application of various models, their modification to fit special circumstances, and the development of new models to describe particular conditions or situations. Markov chains and dynamic programming will be discussed.

[**9527 Theory of Traffic Flow (g).** Spring. Credit three hours. Two lectures. Prerequisite: 9160 or consent of the instructor. Not offered in 1971–72.
Study of various mathematical theories of traffic flow. Microscopic models (car following models). Macroscopic models (kinematic wave theory). Stochastic properties of traffic flow at low density. Probability models for traffic lights and optimal control of signalized intersections. Traffic flow on transportation networks. Application to traffic assignment. Traffic networks simulation system.]

[**9529 Problems and Techniques in Optimization (g).** Spring. Credit three hours. Three lecture-recitations. Prerequisite: 9160 and 9320. Not offered in 1971–72.
Selected topics in the application of operations research techniques to problems encountered in actual situations. Specific topics to be treated, generally related to mathematical programming, are at the discretion of the instructor. Typical of subjects discussed are column generation methods, network algorithms, techniques for handling uncertainty, computation of nonlinear programs, and enumeration methods for integer problems as applied to scheduling, location, distribution, and engineering design problems.]

9530 Mathematical Programming (g). Fall. Credit three hours. Three lecture-recitations. Prerequisite: advanced calculus and basic linear algebra, or 9320. Mr. Eisner.
The dual theorem of linear programming. Geometric and algebraic characterizations of the problem. Adjacent extreme point methods including degeneracy. Data organization for computation. Post-optimality analysis. Transportation and other network programming problems. Primal-dual and decomposition methods. Introduction to two-person games and to integer, nonlinear, and stochastic programming.

9531 Integer Programming (g). Fall. Credit three hours. Three lecture-recitations. Prerequisite: 9530. Mr. Nemhauser.
Discrete optimization. Emphasis is on the linear programming problem in which the variables are restricted to be integers. Theory, computation, and applications will be discussed.

9532 Nonlinear Programming (g). Spring. Credit three hours. Three lecture-recitations. Prerequisite: 9530. Mr. Eisner.
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.

[**9533 Combinatorial Analysis (g).** Fall. Credit three hours. Three lecture-recitations. Not offered in 1971–72.
Incidence systems such as block designs, finite geometries, and other combinational designs, counting and enumeration techniques, combinatorial extremum problems, matroids, coding theory, selected topics in graph theory.]

9534 Graph Theory (g). Spring. Credit three hours. Three lecture-recitations. Mr. Lucas.
Finite, infinite, directed, undirected, combinatorial, and topological graphs. Connectedness, planarity and inbedding problems, enumeration problems, coloring and matching problems, automorphism group of a graph, generalizations of graphs, matrix methods, network problems. Applications to electrical networks, economics, and sociometry.

[**9535–9536 Game Theory I–II (g).** Throughout the year. Credit three hours a term. Three lecture-recitation periods. Prerequisite: Mathematics 411 or consent of the instructor; first term is prerequisite to the second. Not offered in 1971–72.
Two-person-zero-sum games; the minimax theorem, relationship to linear programming. Two-person-general-sum games. Noncooperative *n*-person games; Nash equilibrium points. Cooperative *n*-person games: the core, stable sets, Shapley value, bargaining set, kernel, nucleolus. Games without side payments. Games with infinite numbers of players. Economic market games. Mathematical techniques of game theory.]

9537 Dynamic Programming (u,g). Spring. Credit three hours. Three lecture-recitation periods. Prerequisite: 9160 or 9460; 9320 is desirable. Mr. Nemhauser.
A study of the optimization of sequential or multistage decision processes based upon the application of the dynamic programming principle of optimality. Theory, computation, and applications will be discussed.

[**9538 Game Theory Seminar (g).** Spring. Credit three hours. Prerequisite: 9536 or consent of the instructor. Not offered in 1971–72.
A seminar in which students read and report on current papers of interest in game theory, primarily in the area of *n*-person cooperative theory.]

[**9539 Selected Topics in Mathematical Programming (g).** Spring. Credit three hours. Three lecture-recitations. Prerequisite: 9530 and consent of the instructor. Not offered in 1971–72.
Current research topics in mathematical programming.]

9540–9541 Network Flows and Extremal Combinatorial Problems I–II (g). Throughout the year. Credit three hours a term. Three lecture-recitation periods.

Prerequisite: consent of the instructor; first term is prerequisite to the second. Mr. Fulkerson.
The theory of flows in capacity-constrained networks and related areas in applied combinatorial mathematics. Topics include: maximum flow, feasibility criteria, minimum path, minimum cost flow, maximum dynamic flow, out-of-kilter algorithm, multi-terminal flows, network synthesis, project cost curves, scheduling problems, set representatives, (0,1)-matrices, matchings, packing and covering problems, matroid partition and intersection, flows in infinite graphs, blocking systems, frames, blocking and anti-blocking pairs of polyhedra.

[**9550 Engineering Economic Analysis (g).** Fall. Credit three hours. Three lectures. Not offered in 1971–72.
Use of cost information for financial reporting, cost control, and decision making. Specific topics include theory of double-entry accrual accounting; use of costs in manufacturing; job order *vs.* process costing; predetermined overhead rates; standard costs and variances. Modification of cost information for decision making: cost dichotomies; profit-volume charts; direct costing; costing of joint products and by-products; economic lot sizes; use of costs in other models of operations research. Capital investment planning; the time value of money; use of interest rates; ranking procedures for proposed projects; handling of risk and uncertainty.]

[**9551 Advanced Engineering Economic Analysis (g).** Spring. Credit four hours. Three lectures. Prerequisite: 9311 or equivalent. Not offered in 1971–72.
Topics include capital investment planning procedures, project ranking, interdependence of productive investment, and financing decisions. The cost of capital controversy. Handling of risk and uncertainty. Applications of linear programming to capital budgeting problems. Theory of the firm, including objectives, market structure, and pricing policies. Measures of performance. Problems of profit measurement in the decentralized firm, including discussion of transfer pricing.]

9560 Applied Stochastic Processes (g). Spring. Credit four hours. Three lectures, one recitation. Open to qualified undergraduates. Prerequisite: a good first course in probability (e.g., 9460 or Mathematics 371), or a similar degree of sophistication (e.g., 9160 plus 9361). Mr. Taylor.
An introduction to stochastic processes with emphasis on a variety of applications of the basic theory. The following topics are covered: second order processes; Markov chains and processes; diffusion processes, renewal theory and recurrent events; fluctuation theory; random walks; branching processes; Brownian motion; birth and death processes. Examples are drawn from queuing theory, population growth and other ecological models, inventory theory, etc.

9561 Queuing Theory (g). Fall. Credit three hours. Three lectures. Prerequisite: 9460 and permission of the instructor. Mr. Prabhu.
Definition of a queuing process. Poisson and Erlang queues. Imbedded chains. Transient behavior of the systems M/G/1 and GI/M/1. The general queue GI/G/1. Bulk queues. Applications to specific engineering problems such as shop scheduling, equipment maintenance, and inventory control.

[**9562 Inventory Theory (g).** Spring. Credit three hours. Three lecture-recitations. Prerequisite: 9361 and permission of the instructor. Not offered in 1971–72.
An introduction to the mathematical theory of inventory and production control, with emphasis on the construction and solution of mathematical models. Topics will be drawn from the recent technical literature and will include deterministic and stochastic demands; dynamic programming and stationary analysis of inventory problems; renewal theory applied to inventory problems; multiechelon problems; statistical problems; and production smoothing.]

[**9565 Time-Series Analysis (g).** Fall. Credit three hours. Three lectures. Prerequisite: permission of the instructor. Not offered in 1971–72.
The Hilbert space projection theorem and its application to linear prediction and linear statistical inference. Spectral representations of wide sense stationary processes. Estimation of spectral densities and other topics in empirical spectral analysis. Discussion of several time-series models and the basic statistical techniques associated with the models.]

9569 Selected Topics in Applied Probability (g). Both terms. Credit three hours. Three lectures. Prerequisite: 9560 and permission of the instructor. Messrs. Prabhu and Taylor.
Selected topics in applied probability for advanced students. Topics will be chosen from current literature and research areas of the staff.

9570 Intermediate Statistics (g). Fall. Credit four hours. Three lectures, one recitation. Prerequisite: 9370, 9470, or permission of the instructor. Mr. Brown.
Distributions used in the analysis of the properties of standard statistical tests, including noncentral F distributions. Power of standard statistical tests. Distributions of estimators. Rational choice of sample size. Simple, multiple, and partial correlation. Regression analysis. Tests of goodness of fit.

9571 Design of Experiments (g). Spring. Credit four hours. Three lectures. Prerequisite: 9570 or permission of the instructor. Mr. Bechhofer.
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.

[**9572 Statistical Decision Theory (g).** Spring. Credit three hours. Three lectures. Prerequisite: 9370 and 9570, or equivalent. Not offered in 1971–72.
The general problem of statistical decision theory and its applications. The comparison of decision rules; Bayes, admissible, and minimax decision rules. Problems involving a sequence of decisions over time, including sequential analysis. Use of the sample cumulative distribution function and other nonparametric methods. Applications to problems in the areas of inventory control, sampling inspection, capital investment, and procurement.]

9573 Statistical Multiple-Decision Procedures (g). Fall. Credit three hours. Three lectures. Prerequisite: 9571 or permission of the instructor. Mr. Bechhofer.
The study of multiple-decision problems in which a choice must be made among two or more courses of action. Statistical formulations of the problems. Fixed-sample size, two-stage, and sequential procedures. Special emphasis on applications to ranking problems involving choosing the "best" category where goodness is measured in terms of a particular parameter of interest. Recent developments.

9574 Nonparametric Statistical Analysis (g). Fall. Credit three hours. Three lectures. Prerequisite: 9470 or permission of the instructor. Mr. Weiss.

Estimation of quantiles, c.d.f.s. and p.d.f.s. Properties of order statistics and rank-order statistics. Hypothesis testing in one- and two-sample situations. Large-sample properties of tests and asymptotic distributions of various test statistics.

[9579 **Selected Topics in Statistics (g).** Either term. Credit three hours. Three lectures. Prerequisite: 9570 or permission of the instructor. Not offered in 1971–72. Selected topics chosen from such fields as nonparametric statistical methods, sequential analysis, multivariate analysis.]

9580 **Digital Systems Simulation (g)** Fall. Credit four hours. Two lectures, one recitation. Required of M.Eng. (Industrial) students. Prerequisite: Computer Science 202 and 9370, or permission of the instructor. Mr. Maxwell.
The use of a program for a digital computer to simulate the operating characteristics of a complex system in time. Discussion of problems encountered in construction of a simulation program; synchronization and file maintenance, random-number generation, random-deviate sampling. Programming in simulation languages. Problems in the design of effective investigations using simulation; statistical considerations when sampling from a simulated process.

9582 **Data Processing Systems (g).** Spring. Credit four hours. Two lectures, one computing session. Prerequisite: Computer Science 202 or permission of the instructor. Staff.
The design of integrated data-processing systems for operational and financial control; questions of system organization, languages, and equipment appropriate to this type of application; file structures, addressing, and search problems, sorting techniques; problems of multiple-remote-input, on-line data-processing systems; techniques of system requirement analysis.

[9589 **Selected Topics in Information Processing (g).** Either term. Credit four hours. Two recitations, one laboratory. Prerequisite: Computer Science 202 and permission of the instructor. Not offered in 1971–72. Selected topics in the design of computer systems to implement operations research techniques.]

9590 **Special Investigations in Industrial Engineering and Operations Research (u,g).** Either term. Credit and sessions as arranged. Offered to students individually or in small groups. Registration must be made with the registration officer of the School.
Study, under direction, of special problems in the Field of Industrial Engineering and Operations Research.

9591 **Operations Research Graduate Seminar (g).** Fall and spring. Credit one hour. Staff.
A weekly 1½ hour seminar devoted to presentation, discussion, and study of research in the Field of Operations Research. Distinguished visitors from other universities and institutions, both domestic and foreign, as well as faculty members and advanced graduate students of the Department and the University speak on topics of current interest.

9593–9594 **Industrial Engineering Graduate Seminar (g).** Fall and spring. Credit one hour each term. Messrs. Goode and Saunders.
A weekly meeting to discuss assigned topics and hear presentations of the state of the art from practitioners in the field.

9598–9599 **Project (g).** Fall and spring. Variable credit. A normal requirement of eight credit hours must be completed by each candidate for the professional Master's degree during the last two terms of matriculation. Staff.
Project work requires the identification, analysis, and design of feasible solutions to some loosely structured systems engineering problem. The solutions must be defended on sound engineering and economic grounds.

Materials Science and Engineering

6031 **Structure of Materials I (u).** Fall. Credit three hours. Two lectures, one laboratory.
Structural characterization and properties of materials and basic experimental techniques. Symmetry and structure of crystalline materials, electron and x-ray diffraction techniques, optical and electron microscopy. Amorphous and semicrystalline materials, structure of polymers. Phase diagrams, nonequilibrium structures, precipitation, deformation and annealing, twinning.

6032 **Structure of Materials II (u).** Spring. Credit three hours. Two lectures, one laboratory.
Continuation of 6031.

6034 **Mechanical Properties of Materials (u).** Spring. Credit three hours. Three lectures.
Stress, strain. Elastic stiffness and compliance, anisotropic and isotropic elastic constants. The physical basis of elastic behavior. Crystal plasticity in terms of dislocation theory. The plastic flow of single crystals, Schmidt's law, work hardening. Thermally activated plastic flow. Structural hardening of crystals. Viscosity, Maxwell and Voigt solids. Theory of rubber elasticity and viscous flow of polymers. The glass transition. Unstable flow of crystalline and amorphous solids. Brittle fracture, theoretical cleavage strength, Griffith model of fracture of elastic solids, the plastic work term, concepts of fracture mechanics. Ductile fracture. Creep. Fatigue. Effects of environment on flow and fracture.

6035 **Thermodynamics and Fluid Mechanics (u).** Fall. Credit three hours. Three lectures.
Introduction to classical thermodynamics; kinetic theory of gases and statistical mechanics. Application to engineering problems.

6036 **Thermodynamics of Condensed Systems (u).** Spring. Credit three hours. Three lectures. Prerequisite: 6035.
Review of Zeroth, first, second, and third laws of thermodynamics; fugacity, activity, and the equilibrium constant; first- and second-order phase transformations; classical theory of solutions; heterogeneous equilibrium; free-energy composition diagrams; Einstein and Debye theory of specific heats; quasi-chemical theory of solutions; short-range order; surfaces and interfaces; point defects.

6039 **Materials Engineering (u).** Fall. Credit three hours. Two lectures, one laboratory (alternate weeks).
Selection and processing of materials for engineering applications. The effect of processing on the structure and properties of materials and the control of properties by variations in processing are emphasized. Processing methods considered involve solidification, plastic deformation, heat treatment, material bonding, and consolidation of powders.

6041 **Kinetics (u).** Fall. Credit three hours. Three lectures.
An introduction to the kinetics of atomic transport and transformations in solid materials. Atomistic theory of thermally activated rate processes: theory

of nucleation in vapor, liquid, and solid phases. Thermally activated and athermal growth during transformations. Applications to phenomena such as recovery, recrystallization, and grain growth. Transformations of both the diffusional and martensite type. Solid state capillary phenomena. Oxidation and corrosion.

6042 Electrical and Magnetic Properties (u). Spring. Credit three hours. Three lectures.
An introduction to electrical and magnetic properties of materials with emphasis on structural aspects. Classification of solids; charge and heat transport in metals and alloys; semiconductors and insulators; principles of operation and fabrication of semiconductor devices; behavior of dielectric and magnetic materials; phenomenological description of superconducting materials.

6043–6044 Senior Materials Laboratory (u). Either term. Credit three hours.
Experiments are available in structural studies, properties of materials, deformation and plasticity, mechanical and chemical processing, phase transformations, surface physics, etc.

6045 Materials Processing I (Chemical) (u). Fall. Credit three hours. Three lectures.
Principles of materials processing by chemical techniques, including application of thermodynamic and kinetic principles, heat and mass transfer, and process control. Extraction and refining of metals and ceramics. Production of iron and steel. Advanced techniques, including crystal growth and deposition from the vapor phase. Applications to micro electronic devices and systems.

6046 Materials Processing II (Mechanical) (u). Spring. Credit three hours. Three lectures.
Processing and shaping of materials by mechanical deformation. Elements of plasticity. Material structure and deformation processing methods. Processing as a method of controlling material properties.

6101 Elements of Materials Science (u). Spring. Credit three hours. Mr. Ruoff.
Relations between atomic structure and macroscopic properties of such diverse materials as metals, ceramics, and polymers. Properties discussed include magnetism, superconductivity, insulation, semi-conductivity, mechanical strength, and plasticity. Applications to microelectronics, desalinization by reverse osmosis, superconducting power transmission lines, synthetic bones and joints, etc. Extensive use of modern educational techniques, including slides, audiotutorial systems, movies, student response system.

6261 Mechanical Properties of Materials (u). Either term. Credit three hours. Two lectures, one recitation or laboratory.
Elastic, anelastic, and plastic behavior of crystalline and rubber-like materials; single and polycrystalline materials. Stress-thinning mechanisms, composite materials; fracture, fatigue, and creep. Crystal structure, lattice defects, phase equilibria, diffusion, macrostructure and microstructure from programmed learning sequences. Engineering applications of materials.

6262 Electrical Properties of Materials (u). Spring. Credit three hours. Two lectures, one recitation or laboratory.
Description and understanding of physical properties and applications of electrical materials. Electronic structure of atoms, molecules, and crystalline solids. Energy-band concept applied to insulators, semiconductors, and metals. Semiconductors and applications in electronic devices. Thermoelectricity, dielectrics, and magnetic properties.

Graduate Core Program: Materials Science and Engineering

6601 Topics in Thermodynamics and Kinetics (g). Credit three hours.
Generalization of thermodynamics to include non-chemical forms of energy. Statistical nature of entropy. Phase stability. Defect equilibria. Thermodynamics of solutions, surfaces, and interfaces. Reaction kinetics. Diffusion. At the level of *Introduction to Chemical Physics* by Slater, and *Thermodynamics* by Guggenheim.

6602 Phase Transformations (g). Credit three hours.
Interfaces between phases. Nucleation theory. Growth theory. Formal theory of nucleation and growth transformations. Spinodal decomposition. Diffusionless transformations. Applications of the theory to specific changes in real materials. At the level of *Theory of Phase Transformations in Metals and Alloys* by Christian.

6603 Crystal Mechanics (g). Credit three hours.
Crystal symmetry. Vector fields and tensor fields. Lattice deformation and fault crystallography. Reversible tensor properties of crystals. Relationships between different tensor properties. Crystal elasticity, elastic waves, and polymer elasticity. Lattice dynamics. Thermophysical properties. Irreversible tensor properties. Coupling of transport phenomena. Higher order effects. At the level of *Physical Properties of Crystals* by Nye, *Dynamical Theory of Crystal Lattices* by Born and Huang, and *Wave Mechanics of Crystalline Solids* by Smith.

6604 Dislocations (g). Credit three hours.
Review of geometrical and strain-energy aspects of dislocation theory. Experimental evidence for dislocations. Dislocation strain and stress fields and associated strain energy. Interactions with applied stresses and with other dislocations. Jogs, point defects, and climb. Dislocation sources. Crystallographic aspects such as stacking faults and partial dislocations in specific crystal structures. Grain boundaries. At the level of *Dislocations* by Friedel and *Theory of Crystal Dislocations* by Nabarro.

6605 Electrical and Magnetic Properties of Engineering Materials (g). Credit three hours. Prerequisite, 454 or consent of the instructor.
Electrical properties of semiconductors. Optical and dielectric properties of insulators and semiconductors. Ferrites. At the level of *Introduction to Solid State Physics* by Kittel, *Physics of Magnetism* by Chikazumi, *Superconductivity* by Lynton, and *The Effect of Metallurgical Variables on Superconductivity Properties* by Livingston and Schadler.

6606 Mechanical Behavior of Materials (g). Credit three hours.
Strain hardening. Dislocation dynamical treatment of yield and flow. Polycrystalline hardening. Interaction of interstitial solute atoms with dislocations. Solution hardening. Two-phase hardening. Time- and temperature-dependent deformation. Dislocation models for cleavage of crystals. Viscosity and visco-elastic behavior. Theories of rubber elasticity. Newtonian and nonlinear viscous flow. Creep and creep rupture. Ductile fracture and the fracture of rubber. Fatigue. At the level of review articles in *Progress in Materials Science* and various conference reports.

6611 Principles of Diffraction (g). (Same as Applied and Engineering Physics 8211.) Fall. Credit three hours.
A broad introduction to diffraction phenomena as applied to solid state problems. Production of neutrons and x rays, scattering and absorption of neutrons, electrons, and x-ray beams. Diffraction from two- and three-dimensional periodic lattices. Crystal symmetry, Fourier representation of scattering centers and the effect of thermal vibrations on scattering. Phonon information from diffuse x-ray and neutron scattering and Bragg reflections. Standard crystallographic techniques for single crystals and powders. Diffraction from almost periodic structures, surface layers, gases, and amorphous materials. A survey of dynamical diffraction from perfect and imperfect lattices. Techniques for imaging structural defects. Selected experiments illustrating diffraction effects. At the level of *Electron Microscopy of Thin Crystals* by Hirsch, Howie, Nicholson, Pashley, and Whelan.

For the Professional Master's Degree

6503 Metals Selection and Use (g). Fall. Credit three hours. Three lectures. Prerequisite: 6032.
Metallurgical and mechanical factors governing the selection of metals for various services. Analysis of service requirements and the selection and fabrication of metals to fulfill such requirements; analysis of service failures of metals and remedies for such failures; and study of the merits and limitations of materials applications in existing products and equipment.

6553–6554 Project (g). Fall and spring. Credit six hours.
Research on a specific problem in materials or metallurgical engineering.

6555 Materials Processing (g). Spring. Credit three hours. Three lectures.
The principles of materials processing including both metallic and nonmetallic materials. The control of materials properties and various solutions to engineering problems of shaping, making, and treating are stressed.

Other Graduate Courses

6612 Selected Topics in Diffraction (g). (Same as Applied and Engineering Physics 8212.) Spring. Credit three hours. Three lectures. Prerequisite: 8211 or consent of the instructor.
The Ewald-von Laue dynamical theory applied to x-ray and high-energy electron diffraction in solids. Thermal scattering and measurement of phonon dispersion, frequency spectrum, interatomic force constants, Debye temperatures and vibrational amplitudes. Diffuse scattering, short- and long-range order, precipitation in solids, point defects.

6614 Electron Microscopy (u,g). Credit three hours.
Electron optics. Kinematical theory of diffraction with applications to the appearance of stacking faults, dislocations, inclusions, etc. Dynamical theory of diffraction as applied to the calculation of contrast from various defects. Interpretation and analysis of electron diffraction problems. Application of the stereographic projection to problems in microscopy (e.g., indexing of diffraction patterns from single crystals containing oriented second phases). Applications of dark field microscopy. Instruction in the use of the microscope.

6625 Composite Materials (u,g). (Same as Theoretical and Applied Mechanics 1280.) Spring. Credit three hours. Staff: faculty from Materials Science and Engineering and Theoretical and Applied Mechanics; guest lecturers.
The physical basis of the strength, elastic modulus, and fracture resistance of composite materials; the micro- and macro-mechanics of composites, their mechanical response, and important composite systems including fabrication, processing, and design applications. Compatibility and interaction of fibers and matrix. Fatigue, creep, fracture mechanisms. Analysis of primary configurations such as tension and compression members, beams, and plates including such local effects as bonding, fiber-tip stress concentration, buckling.

6762 Physics of Solid Surfaces (g). (Same as Applied and Engineering Physics 8262). Spring. Credit three hours. Three lectures.
Equilibrium thermodynamics and statistical mechanics of interfaces. Diffuse interfaces, crystal surfaces, anisotropy and orientation dependence of surface properties, Wulff diagrams. Atomic structure of surfaces in equilibrium. Surface fields, dipoles and defects in insulators. Electronic and vibrational properties of surfaces. Surface barriers and work functions, surface vibrational and electronic states. Kinetic processes at surfaces. Mass and charge transport in the surface region. Condensation and evaporation processes. Experimental techniques: discussion of LEED, FIM, FEM, etc. Materials drawn from research papers and various review articles in journals such as *Progress in Materials Science, Advances in Chemistry, Solid State Physics,* and specialized texts such as *Semiconductor Surfaces* by Many, Goldstein, and Grover, and *Atomic and Ionic Impact Phenomena* by Kaminsky.

6764 Fracture of Materials (g). Credit three hours. Three lectures.
Mechanics of fracture. Griffith theory. Crack-tip stresses and strains. Crack-tip plasticity. Macroscopic aspects of fracture in crystalline and noncrystalline materials. Dislocation models. Void growth. Special topics such as fatigue, environment and fracture, fracture testing. Material from various conference reports; *Fracture of Structural Materials* by Tetelman and McEvily, and *Strong Solids* by Kelly.

6765 Amorphous and Semicrystalline Materials (g). Credit three hours. Three lectures.
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, *Non-Crystalline Solids* by Frechette, and *The Physics of Rubberlike Elasticity* by Treloar.

6766 Materials Science Seminar (g). Credit two hours. One seminar period.
Topics selected from current research interests of the faculty.

6873 Materials Science for Engineers (g). Credit three hours. Three lectures.
Structure of crystals. Crystal lattice properties. Crystal defects (point, line, planar). Thermodynamics of solids. Diffusion and kinetics (emphasis on defect annealing, e.g., polygonization, recrystallization, grain growth, point defect recovery, etc.). Mechanical properties (role of crystal defects in plastic deformation, creep, fracture). Topics in radiation damage including defect production, radiation damage annealing, and effect of damage on physical properties.

Mechanical Engineering

The courses in mechanical engineering are listed under the following headings: *General, Mechanical Systems and Design (Engineering Design; Materials Processing),* and *Thermal Engineering.*

General

3020 The Age of Power—A History of Technology (u). Spring. Credit three hours. Three lecture-discussions. Mr. Conta.
A history of technology traced from its origin before the dawn of history and ending with modern industrial society. Emphasis will be upon the nineteenth and twentieth centuries and what has been called the second revolution in power—the vast increase in available power made possible by the development of the Watt steam engine and the exploitation of the thermal energy of wood and the fossil fuels. The relationship of this technology to other technologies and to the economic, social, and political developments of the period.

3053 Mechanical Engineering Laboratory (u). Fall. Credit four hours. One lecture, two laboratories. Prerequisite: 3325, 3621, 3623, and simultaneous registration in 3326 and 3625.
Laboratory exercises in instrumentation, techniques, and methods in mechanical engineering. Measurement of pressure, temperature, heat flow, mass transfer, displacement, force, stress, strain, vibrations, noise, etc. Use of electronic instruments and fast-response sensors for steady and transient states. Use of density-sensitive optical systems. Error analysis in experimental determinations.

3054 Design of Mechanical Engineering Systems (u). Spring. Credit four hours. Two lectures, two design periods. Prerequisite: 3326 and 3625.
Design experiences in the conception of machines and mechanical engineering systems. The determination of size from thermal or fluid-flow considerations. The conception of configuration from considerations of motion, strength, rigidity, and vibration. Selection of materials and mechanical components, including regard for thermal and corrosive environments. Design considerations for the processing of components and their assembly. Feasibility studies and preliminary designs by sketches and layouts.

3090–3091 Mechanical Engineering Design Project (g). Fall and spring. Credit three hours. Intended for students in the M.Eng. (Mechanical) program.
Design of an engineering system or a device of advanced nature. Projects to be carried out by individual students or by small groups with individual assignments culminating in an engineering report by each student. In some cases the project is carried out in collaboration with an external organization, such as an industrial company, research laboratory, or public agency, whose representatives suggest current problems and review the final designs.

Mechanical Systems and Design

Engineering Design

See also Courses 3054, 3090, 3091 under the heading "General" above.

3301 Naval Ship Systems (u). Spring. Credit three hours. Open to freshmen and sophomores only.
An introduction to primary ship systems and their interrelation. Basic principles of propulsion, control, internal communications, structure, and other marine systems are considered.

3325 Mechanical Design and Analysis (u). Fall and spring. Credit four hours. Three recitations, one laboratory. Prerequisite: 1031.
Application of the principles of mechanics and materials to problems of analysis and synthesis of mechanical systems. Topics considered vary from year to year and range from traditional discipline-oriented work to work cutting across several disciplines. Laboratory considers open-ended design problems and problems of physical measurement.

3326 Systems Dynamics (u). Fall and spring. Credit four hours. Three recitations, one laboratory. Prerequisite: 3325.
Consideration of the dynamic behavior of systems with emphasis on modeling and analysis techniques and their application. Discipline-oriented topics include analog- and digital-computer simulation; frequency and transient response of linear systems, scalar and vector/matrix models, and dynamic measurement of physical quantities. Laboratories include physical experiments, computer simulations, and design of systems for specified dynamic performance. Applications are drawn chiefly from vibration and control systems.

3361 Advanced Mechanical Analysis (g). Fall. Credit three hours. Three recitations. Intended for graduate students in the M.Eng. (Mechanical) program.
Advanced topics in mechanical design. Selected topics from design optimization, design reliability, advanced kinematics, systems analysis, computer-aided design, advanced strength of materials.

3363 Mechanical Components (u,g). Spring. Credit three hours. Three recitations. Prerequisite: 3325 or equivalent. Mr. Burr.
Advanced analysis of machine components and structures. Application to the design of new configurations and devices. Lubrication theory and bearing design. Fluid couplings, torque converters, speed-control devices. Shell, thick-cylinder, and elastic foundation theory and design of pressure vessels, rotating disks, and fits. Elastic-plastic design, thermal stresses, creep and relaxation. Impact.

3364 Design for Manufacture (u,g). Fall. Credit three hours. Three recitations. Prerequisite: 3401 or 6261, or concurrent with 3401, or permission of the instructor. Messrs. Burr and Wang.
Design of castings, forgings, stampings, and weldments; unconventional processes. Design for heat treatment, machining, and assembly; selection of materials; dimensioning and fits, jigs and fixtures. Joints, fasteners, and shaft mountings and connections. Specifications for manufacturing and maintenance to minimize fatigue failures and improve reliability; beneficial prestressing; improving the distribution of loads and deflections. Seals and lubrication systems. Components and circuits for fluid power and controls. Short design problems.

3365 Biomechanical Systems—Analysis and Design (u,g). Spring. Credit three hours. Three recitations. Prerequisite: 1021, 1031. Mr. 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. Investigation of normal and impaired biomechanical systems. Analysis and design of assistive (orthotic) and replacement (prosthetic) devices for impaired biomechanical systems. Analysis and design of man/machine systems used in orthopedic surgery and physical rehabilitation.

[3366 **Advanced Kinematics (u,g).** Fall. Credit three hours. Two recitations, one computing. Prerequisite: 3325. Not offered 1971–72.
Advanced analytical and graphical determination of velocities and accelerations in mechanisms. Special geometrical concepts on the kinematics of mechanisms. Synthesis of linkages by graphical and analytical methods. Design of linkages to give prescribed paths, positions, velocities, and accelerations.]

3368 **Mechanical Vibrations (g).** Spring. Credit three hours. Two recitations, one laboratory. Open to qualified undergraduates. Prerequisite: 3326 or equivalent.
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. Also gyroscopic effects, branched systems, random vibrations, impact and transient phenomena, isolation of shock vibration, and noise and its reduction. Impedance, matrix, and numerical methods. Analog- and digital-computer solutions and laboratory studies.

3372 **Experimental Methods in Machine Design (g).** Fall. Credit three hours. One recitation, two laboratories. Prerequisite: 3325 or equivalent. Mr. Phelan.
Investigation and evaluation of methods used to obtain design and performance data. Techniques of photoelasticity, strain measurement, photography, vibration and sound measurements, and development techniques as applied to machine design problems.

3374 **Conceptual Design (g).** Fall. Credit three hours. Three recitations. Prerequisite: 3325 or equivalent. Open to undergraduates with permission of instructor. Mr. Oldberg.
A treatment of the processes of advanced system or new product evolution as practiced by industry, including product planning, creation of ideas, synthesis into working concepts, and evaluation. A working exposure to engineering components. Numerous projects, much discussion, some lectures.

3375 **Automatic Machinery (u).** Spring. Credit three hours. Two recitations, one field trip. Prerequisite: 3325. Mr. Wehe.
A study of automatic and semiautomatic machinery such as dairy, canning, wire-forming, textile, machine tool, computing, and printing equipment.

3377 **Automotive Engineering (u,g).** Spring. Credit three hours. Three recitations. Prerequisite: 3325. Mr. Oldberg.
A discussion of the important motor vehicle design parameters and major components, including engine, driveline, brakes, suspension, handling, and structure. Emphasis is placed on the influence of design variables on performance and of basic ideas and alternatives. Lectures, discussion, term paper.

3378 **Automatic Control Systems (g).** Spring. Credit three hours. Two recitations, one laboratory. Open to qualified undergraduates. Prerequisite: 3326 or equivalent.
Further development of feedback control theory, including stability criteria, frequency response, and transfer functions, with emphasis on engineering problems involving the analysis of existing control systems and the design of systems to perform specified tasks. Nonlinear systems describing functions, sampled-data systems, and compensation techniques. Analog-computer simulation and laboratory studies of hydraulic, pneumatic, and electromechanical components and systems.

3380 **Design of Complex Systems (g).** Fall. Credit three hours. Two meetings of two hours per week to be arranged. Prerequisite: permission of instructor. Mr. Wehe.
A seminar course relying heavily on student participation in discussing frontier problems such as systems for space and underwater exploitation, salt water conversion, and transportation. Determination of specifications for these systems to meet given needs. Critical discussion of possible solutions based on technical as well as economic and social considerations. Reports which set forth recommendations and the reasoning leading to them will be required.

3382 **Hydrodynamic Lubrication (g).** Spring. Credit three hours. Three recitations. Mr. 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 films, bearing-system dynamics, and digital and analog computer solutions. Also, selected special topics in elasto-hydrodynamic, thermo-hydrodynamic, and magneto-hydrodynamic lubrication.

3385 **Optimum Design of Mechanical Systems (g).** Fall. Credit three hours. Three recitations. Mr. Bartel.
The formulation, as optimization problems, of design problems frequently encountered in mechanical systems. Emphasis is on the choice of the design objective function and the constraints. Finite and infinite dimensional design problems. Theory and application of methods of mathematical programming to the solution of optimum design problems. Examples will be drawn from structures and machine components frequently encountered in mechanical systems.

3387 **Dynamics of Vehicles (u,g).** Fall. Credit three hours. Prerequisite: 1021 and 1031 or equivalents, and permission of instructor. Mr. Krauter.
Intended as an introduction to the dynamics of automobiles and trucks. Emphasis is on the handling behavior of the automobile. Tire theory and suspension analysis. Also, articulated vehicle handling, motorcycle dynamics, and vehicle safety.

3388 **Computer Simulation and Analysis of Dynamic Systems (g).** Spring. Credit three hours. Three recitations. Open to qualified undergraduates by permission of instructor. Some introductory acquaintance with systems dynamics and digital programming areas is assumed. Mr. Booker.
Modeling and representation of physical systems by systems of ordinary differential equations in 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. At the level of *Elements of Control Systems Analysis, Part II,* by Chen and Haas; and *Elementary Numerical Analysis* by Conte.

3390 **Special Investigations in Mechanical Systems (u,g).** Either term. Credit arranged. Permission of Department head required.
Individual work or work in small groups under guidance in the design and development of a machine, in the analysis of experimental investigation of a machine or component, or in studies in a special field of mechanical systems.

3392 **Special Topics in Engineering Design (u,g).** Either term. Credit one hour or more. Ten to 15 lecture periods per term on a topic of special interest not requiring a course of standard length. Hours to

be arranged. Department to be consulted before registration.
Series of lectures by staff members or visiting staff on subjects of current interest. Topics will be announced prior to beginning of term. More than one topic may be taken if offered.

Materials Processing

3401 Materials and Manufacturing Process (u). Fall and spring. Credit three hours. Two lectures and one laboratory. Prerequisite: 1021. Mr. Wang.
Comprehension of material structures. Physical and metallurgical properties of materials, and their control by mechanical and metallurgical means. Conventional and unconventional manufacturing processes. Emphasis is placed on the applications of the knowledge learned in core courses and the correlations among design, material properties, and processing methods.

3451 Analysis of Manufacturing Processes (u,g). Spring. Credit three hours. Three recitations. Prerequisite: 3401. Mr. Wang.
Analytical treatment of the processes of material removal and plastic deformation, from the interdisciplinary viewpoints of mechanics, thermodynamics, and metallurgy. Emphasis is placed equally on conventional and unconventional processes involving ultrasonic, high-energy beam, electric-discharge, and electrochemical energy sources. Also, economic analysis of production-system and machine-tool dynamics.

[**3461 Quality Assurance Systems (u).** Either term. Credit three hours. Two lectures, one laboratory. Prerequisite: 3401. Staff. Not offered in 1971–72.
Theory and computational techniques for control by attributes or variables. Machine-tool capability studies, instrumentation systems. Standards, codes, and applications. Equipment-performance characteristics. Fixed and comparative gaging systems; noncontract, reflective, and radiation principles. Surface texture phenomena. True-position tolerancing and charting.]

3475 Introduction to Numerical Control (u,g). Fall. Credit three hours. Three recitations. Mr. Wang.
A broad introduction to numerical control technology, covering both hardware and software aspects. Principles of conventional numerical control systems, adaptive control, and direct computer control of machine tools. Manual and computer-aided part programming methods. Extensive exercises in APT programming. Methodology for economic justification.

3490 Special Investigations in Materials Processing (u,g). Either term. Credit to be arranged. Mr. Wang.
Independent study of selected topics concerned with analytical or experimental investigation of manufacturing processes. Design, manufacture, and test of a machine or a component to be used for materials processing. Topics will include production systems, quality assurance, metrology, or machine tools, in accordance with individual interests. Work will be carried out individually or, for relatively large-scale projects, in small groups.

Thermal Engineering

3621 Thermodynamics (u). Fall and spring. Credit three hours. Three recitations. Prerequisite: Mathematics 191 and 192, Physics 112 and 213.
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.

3623 Fluid Mechanics (u). Fall and spring. Credit four hours. Four recitations. Prerequisite: 1031 and 3631.
Properties of fluids, fluid statics; kinematics of flow, elements of hydrodynamics; dynamics of flow, momentum and energy relations, Euler equations, wave motion; thermodynamics of flow; shocks and gasdynamics; dimensional analysis; real fluid phenomena, laminar and turbulent motion; compressible flow in ducts with area change, friction, and heating; laminar and turbulent layer, lift and drag; supersonic flow.

3625 Heat Transfer and Transport Processes (u). Fall. Credit three hours. One lecture, two recitations. Prerequisite: 3631, 3623.
Conduction of heat in steady-state, unsteady-state and periodic heat flow; analogic methods; numerical methods; fin surfaces; systems with heat sources. Convection; boundary layer fundamentals; natural convection; forced convection inside tubes and ducts; forced convection over various surfaces. Boiling and condensation. Radiation: emission, absorption, reflection, transmission, and exchanges. Radiation combined with conduction and convection. Heat exchangers; overall heat transfer coefficients; mean-temperature difference; effectiveness; design.

3631 Introduction to Thermodynamics (u). Fall and spring. Credit three hours. Three recitations.
Similar to 3621, but offered as a sophomore core science.

3641 Power Systems (u). Spring. Credit three hours. Prerequisite: 3631 and 3623 or equivalent. Messrs. Moore and Shepherd.
A broad survey of methods of large-scale power generation, emphasizing energy sources, thermodynamic and fluid mechanical cycle considerations, and component description. Terrestrial and space applications. Power industry and economic factors. Long-range trends and projections. Fossil-fueled steam-turbine systems. Exhaust and cooling problems and methods. The gas turbine and water turbine. MHD ducts. Topping units. Nuclear systems. Liquid-metal fast breeder. Gas-core fission and plasma-fusion possibilities. Electro-fluid generator. The chemical laser. Solar energy; heat rejection to space.

3642 Pollution Control in Power and Propulsion (u). Spring. Credit three hours. Three recitations. Prerequisite: 3623 concurrently or permission of the instructor. Staff.
The major sources of general power and motive power are also sources of air pollution, thermal pollution, and noise. Abatement techniques for these pollutants must be developed if we are to satisfy demands for more power while preserving our environment. The main objective of this course is to provide an introduction to the major problems associated with each of these types of pollution and to possible methods of control. Emphasis will be on the fundamental technical aspects of the problems and their solutions. The course will also provide an introduction to the various engineering sciences which form a basis for control technologies.

3651 Advanced Thermal Science (g). Spring. Credit three hours. Three recitations. Prerequisite: 3623, 3625, or equivalent. Intended for graduate students in the M.Eng. (Mechanical) degree program.
Advanced-level study of topics from thermodynamics, fluid mechanics, and heat transfer. Selection of subjects from irreversible thermodynamics, statistical mechanics, real gas behavior, chemical thermodynamics, unsteady flow phenomena, gas dynamics,

turbulent flow of jets and wakes, compressible boundary layer, numerical methods, and variable transport properties.

3652 Combustion Systems (u). Fall. Credit three hours. Three recitations. Prerequisite: 3623 or 3623 concurrently. Mr. Torrance.
Survey of flame processes; analysis of combustion systems. Classification of fuels. Concepts of thermochemical equilibrium, heat of reaction, and flame temperature. Nonequilibrium effects. Performance of combustion systems is examined by considering several contemporary engineering applications; examples are gas turbines, internal combustion engines, rockets, and fossil-fueled power stations. Sources of undesirable exhaust emissions are traced.

3654 Refrigeration and Air Conditioning (u). Spring. Credit three hours. Prerequisite: 3625 or 3625 concurrently. Mr. Fairchild.
Introduction to refrigeration and air conditioning with emphasis on applications of thermodynamics, fluid mechanics, and heat transfer. Compression and other systems of refrigeration; control of the physical environment.

3656 Advanced Thermal Engineering Laboratory (u,g). Fall and spring. Prerequisite: 3053 or equivalent.
A course of individually offered experimental studies prepared and supervised by faculty of the Department of Thermal Engineering, and elected by graduate or undergraduate students. The time allotted, and the number of students accepted for each experiment will be specified by the instructor in each case. Available experiments will range from performance testing of engine components to studies of laser interferometry.

3659 The Nature of Thermodynamics (u,g). Fall. Credit three hours. Three recitations. Prerequisite: a course in thermodynamics or permission of the instructor. Mr. Conta.
A study of the history, philosophy, and mathematics of thermodynamics with emphasis on its scope and limitations. A study of the methods of exposition of the concepts and laws of thermodynamics; a comparison of the intuitive, the axiomatic, and the statistical approaches. The course will be principle rather than problem oriented, and each student will be expected to develop a special topic in thermodynamics, present it orally, and write a term paper in place of a final examination.

3663 Turbomachinery (u,g). Fall. Credit three hours. Three recitations. Prerequisite: 3631, 3623, or permission of instructor. Mr. Shepherd.
Aerothermodynamic design of turbomachines in general, followed by consideration of specific types: fans, compressors, and pumps; steam, gas, and hydraulic turbines. Energy transfer between a fluid and a rotor; flow in channels and over blades. Compressible flow, three-dimensional effects, surging and cavitation. Outline design of a high-performance compressor-turbine unit.

3665 Transport Processes (u,g). Fall. Credit three hours. Three recitations. Prerequisite: basic thermodynamics and fluid mechanics. Mr. Gebhart.
Description of modes of thermal and mass diffusion and transport. Formulation of the transport equations and their use in engineering and in environmental studies. Conduction and mass diffusion in solid materials. Thermal radiation exchange among assemblies of radiating bodies and as a diffusion process. Nature of nonopaque radiation interaction. Energy and mass diffusion by molecular and turbulent processes in convection. Regimes of transport. Consideration of convection resulting from buoyancy forces and from other forcing conditions in fluids. Various aspects of buoyancy-induced flows emphasized in relation to applications.

3667 Physics of Air Pollutants and Their Production (g). Fall. Credit three hours. Three recitations. Mr. Gouldin.
A fundamental treatment of selected physical and chemical topics pertinent to an understanding of gaseous air pollution and its control. Topics include: chemical equilibrium, kinetic theory, statistical calculation of thermodynamic properties of gases, spectroscopic determination of atomic and molecular properties, reaction kinetics, heats of reaction, and adiabatic flame temperatures. Examples will be selected to illustrate the production and properties of particular pollutants. The course will provide a basis for advanced work in air pollution, as well as in related areas such as power and propulsion, high-temperature gas dynamics, and fire research and combustion.

3668 Flame Dynamics (g). Spring. Credit three hours. Three recitations. Prerequisite: preparation at the level of 3667. Mr. Torrance.
A fundamental examination of the fluid mechanics, heat transfer, mass transfer, and reaction kinetics associated with flames. Governing equations are developed and applied to flames of deflagration, detonation, and diffusion types. Ignition, quenching, and turbulence effects are examined. Additional topics include flame stabilization, burning limits, and explosions. Kinetic, thermal, and diffusion control of flames is illustrated with examples selected from environmental combustion problems such as incomplete burning and nitric oxide production in power and propulsion systems, and the spread, containment, and steady burning of destructive fires.

3669 Combustion Engines (u). Fall. Credit three hours. Three recitations. Prerequisite: 3625 or 3625 concurrently. Mr. Fairchild.
Introduction to combustion engines with emphasis on application of thermodynamics, fluid dynamics, and heat transfer; reciprocating combustion engines; gas turbines; compound engines; reaction engines.

3671 Aerospace Propulsion Systems (u,g). Spring. Credit three hours. Three recitations. Prerequisite: 3631, 3623 or permission of instructor. Mr. Shepherd.
Application of thermodynamics and fluid mechanics to the design and performance of thermal-jet and rocket engines in the atmosphere and in space. Mission analysis in space as it affects the propulsion system. Consideration of auxiliary power supply; study of advanced methods of space propulsion.

3672 Energy Conversion (u,g). Spring. Credit three hours. Three lectures. Open to qualified undergraduates. Prerequisite: 3631 or equivalent. Mr. Conta.
Primarily an analysis of energy conversion devices as classified into heat engines, chemical engines, and expansion engines. An analysis of each class from the point of view of efficiency and other criteria of performance. A more detailed study of some conventional and direct energy conversion devices including thermoelectric, thermionic, and photovoltaic converters and fuel cells. Energy sources and energy storage, application to terrestrial and space power systems.

[**3674 Flowing Gas Lasers (g).** Fall. Credit three hours. Three lectures; laboratory hours to be ar-

ranged. Prerequisite: 3623, Physics 443, or consent of instructor. Mr. Cool. Not offered in 1971–72.
A comprehensive treatment of the principles of operation of continuous-wave chemical lasers, fluid mixing lasers, and gasdynamic lasers. There will be an opportunity during the term for experimental laboratory studies of a high power, purely chemical DF-CO_2 laser. Topics include: fluid mechanics of the production of population inversions by rapid mixing, chemical reaction, detonation waves, and Prandtl-Meyer expansion; vibrational energy transfer processes in chemical and molecular lasers; chemical kinetics of atom-exchange reactions; chain-reaction mechanisms; gain saturation and power-output characteristics of high-speed flow lasers; optical design of transverse axis flow laser resonators; survey of current developments in flowing gas lasers; laser-induced fluorescence spectroscopy.]

3675 Dynamics of Rotating Fluids (g). Credit three hours. Three lectures. Prerequisite: 7301 and 1182 or consent of instructor. Mr. Leibovich.
Review of classical fluid mechanics. Rotating coordinate systems. Linearized theory for rapidly rotating fluids. Inviscid regions, viscous layers. Large-amplitude steady motions past objects. Unsteady motions. Small amplitude waves. Wave motion in anisotropic, dispersive media. Phase and group velocity. Kinematic wave theory and energy propagation. Nonlinear waves in rotating fluids. "Vortex breakdown" in tornados and other swirling flows. Theories of vortex breakdown. Boundary layer interactions. Spin-up of fluids in rotating containers. A theoretical course designed for engineers and scientists interested in such applications as fluid motions in rotating containers, geophysical fluid mechanics, energy and mass separation in vortex tubes, etc. Some simple laboratory demonstrations of fundamental phenomena are included.

3676 Applications of Fluid Mechanics (u,g). Spring. Credit three hours. Three recitations. Prerequisite: 3623 or equivalent. Mr. Moore.
A descriptive survey of fluid mechanics organized according to application. Acoustics, flight aerodynamics, aircraft stability and performance, propulsion problems, shocks, detonations and blast waves, hypersonic entry, droplets, oceanography and marine systems, biofluid mechanics, and aspects of meteorology and astrophysics are considered. Intended for seniors, but interested graduate students may attend. Midterm and final reports are required, each treating in depth a topic chosen by the student.

3677 Numerical Methods in Fluid Flow and Heat Transfer (g). Spring. Credit three hours. Three recitations. Prerequisite: familiarity with the partial differential equations of fluid mechanics and basic Fortran programming. Mr. Torrance.
Finite-difference and finite-element methods are developed for solving multidimensional fluid flow and heat transfer problems. Basic principles are stressed, enabling the methods to be extended to problems involving chemical reactions, mass diffusion, or variable properties. Physical and numerical restraints imposed on transient and steady-state numerical solutions are determined. Recent methods are surveyed and compared. Selected examples illustrate applications involving natural convection, flow over objects and within channels, planetary atmospheres and interiors, and flame spread. Assigned problems and the final examination require solution of fluid flow problems on a digital computer.

3679 Inviscid Flow Theory (g). Spring. Credit three hours. Three recitations. Taught in alternate years. Intended to cover inviscid fluid mechanics for students who have taken 7301, and who intend to study flows with viscosity and heat conduction as presented in 7304 and 3680. Mr. Moore.
Potential theory, including distributions of singularities, transformations, wings and cascades, slender-body theory, compressibility; gasdynamics and supersonic flow, including shocks and expansions, characteristics, blast waves, small-disturbance theory; multicomponent flows and stability, including continuous and discontinuous stratification, and the effects of gravity, surface tension, and compressibility on the stability of such flows.

3680 Convection Heat Transfer (g). Spring. Credit three hours. Prerequisite: 3665 or consent of the instructor. Mr. Gebhart.
The diffusion of thermal energy, mass, and momentum are considered. Basic equations are developed and applied to problems of current importance in technology and in environmental and ecological studies. Natural convection (buoyancy-induced) flow is considered in detail. Convection layers adjacent to surfaces, freely rising plumes, buoyant jets, and thermals in extensive media (including stratified media) are treated for laminar and turbulent mechanisms. The conversion of laminar flow to turbulence through instability and transition is treated in detail. Also studied are transient flows, thermal instability and resulting flows, diffusion characteristics in naturally occurring bodies of fluid, and forced flows and resulting convection, including effects of appreciable variation of properties and viscous dissipation. The nature of convection in flows that are driven by both buoyancy forces and imposed conditions, such as flows in the atmosphere and adjacent to heated surfaces, are discussed, and the limits and mechanisms of these mixed flows are given. Emphasis in the course is on analysis, on classification of convection regimes, and on the comparison of analytical results with observations.

3682 Seminar in Heat Transfer (g). Spring. Credit three hours. Two-hour meetings weekly to be arranged. Prerequisite: permission of professor in charge. Mr. Gebhart.
Discussion of fields of active inquiry and current interest in heat transfer. Considerations of major recent work and several summaries of associated contributions.

3685 Nonlinear Wave Propagation (g). Spring. Credit three hours. Three lectures. Prerequisite: an acquaintance with the Fourier transformation and integration in the complex plane. Mr. Leibovich.
Emphasis is on mathematical treatment of nonlinear effects associated with waves in continua. Some particular examples discussed are taken from water waves, gasdynamics, elasticity, plasma physics, and electromagnetic theory. Topics include: Fourier analysis of linear waves; phase and group velocity; dispersion; energy propagation; caustics; kinematic waves; high frequency expansions, diffraction, and ray theory. Nonlinear hyperbolic systems; characteristics; shock waves; energy dissipation; the Burger's equation and its solution. Conservative dispersive systems. The Korteweg-deVries equation and the GGKM method of solution. Nonlinear WKB approximation. Variational principles and Hamiltonian equations for nonlinear dispersive waves. Conservation of wave action. Nonlinear group velocity. Resonant wave interactions and instability of deep water waves.

3690 Special Investigations in Thermal Engineering (u). Fall and spring. Credit by arrangement.
Intended either for informal instruction of a small number of students interested in work to supplement that given in regular courses or for a student wishing to pursue a particular investigation outside of regular courses. Permission of the Department required for registration.

Mechanical Systems and Design

See p. 92.

Nuclear Science and Engineering

See course descriptions for *Applied and Engineering Physics,* p. 57.

Operations Research

See course descriptions for *Industrial Engineering and Operations Research,* p. 85.

Structural Engineering

See p. 69.

Theoretical and Applied Mechanics

For Undergraduates Only

293–293H Engineering Mathematics (u). Either term. Credit four hours. Prerequisite: 192 or 194. 293H is an Honors section, offered in the fall term only. Either term: lectures, M W F 10:10, 12:20; recitation periods to be arranged. Preliminary examinations: at 7:30 p.m. on Oct. 12, Nov. 9, Dec. 7 (fall term) and on Feb. 29, Mar. 21, May 2 (spring term).
Vectors and matrices, first-order differential equations, infinite series, complex numbers, applications. Problems for programming and running on the automatic computer will be assigned, and students are expected to have a knowledge of computer programming equivalent to that taught in Engineering 104.

294–294H Engineering Mathematics (u). Either term. Credit three hours. Prerequisite: 293. 294H is an Honors section, offered in the spring term only. Either term: lectures, M W 10:10, 12:20; recitation periods to be arranged. Preliminary examinations: at 7:30 p.m. on Oct. 5, Nov. 2, Nov. 30 (fall term) and on Feb. 22, Mar. 14, Apr. 22 (spring term).
Linear differential equations, quadratic forms and eigenvalues, differential vector calculus, applications.

1001 Introduction to Applied Mechanics (u). Fall and spring. Credit three hours. Two lectures, one recitation, demonstration laboratory four times per term. Prerequisite: registration in Mathematics 293.
Introduction to technical theory of mechanical behavior of rigid and deformable solids. Principles of mechanics, statics, dynamics. Kinematics and kinetics of a particle, a system of particles, and a rigid body. Methods of analysis including energy and momentum. Mechanics of deformable solids. Kinematics and strain, forces and stress, the constitutive relation. Elasticity, plasticity, viscoelasticity. Rods, beams, tubes, stresses, and deformations. At the level of *Introduction to Engineering Mechanics* by Huddleston.

1021 Mechanics of Solids (u). Fall and spring. Credit three hours. Two lectures, one recitation; demonstration laboratory four times per term. Prerequisite: registration in Mathematics 293.
Principles of statics, force systems, and equilibrium. Mechanics of deformable solids, stress, strain, statically determinate and indeterminate problems. Analysis of slender bars, shearing force, bending moment, singularity functions. Plane stress, transformation of stress, Mohr's circle of stress and strain. Stress-strain–time-temperature relations, elasticity, plasticity, viscoelasticity. Bending and torsion of slender bars; stresses, deformations, and plastic behavior. Virtual work, energy methods, and applications. At the level of *An Introduction to the Mechanics of Solids* by Crandall and Dahl.

1031 Dynamics (u). Fall and spring. Credit three hours. Two lectures, one recitation; demonstration laboratory four times per term. Prerequisite: registration in Mathematics 293.
Principles of Newtonian dynamics of a particle, systems of particles, and a rigid body. Kinematics, frames of reference, motion relative to a moving frame, impulse, momentum, energy. Laws of motion of a system, center of mass, total kinetic energy, moment of momentum, constraints. Rigid body kinematics, angular velocity, moment of momentum and the inertia tensor, Euler equations, the gyroscope. Advanced methods in dynamics. Generalized coordinates, Lagrange's equations, the potential energy function, the kinetic energy function, applications. At the level of *Applied Mechanics-Dynamics* by Housner and Hudson.

Engineering Mathematics

1126–27 Mathematical Concepts in Science and Technology (u,g). Fall and spring. Credit three hours per term. Three lectures. Minimal prerequisite: one year of mathematical methods at or beyond the level of 1150–51. Open to graduate students or to undergraduates with the consent of the instructor. M W F 1:25. Evening exams. Mr. Dunn.
Primarily for students of engineering and the physical sciences. Intended to encourage study of modern abstract mathematics and its relationship to science and technology. Considers various applied problems and methods from the standpoint of underlying abstract mathematical similarity and follows with an introductory treatment of unifying concepts from modern analysis and algebra. Topics will include: the real-complex embedding and its significance for the theory of power series, linear differential equations, and operational (transform) calculus; the theory of contraction mappings on metric spaces and its relation to various iterative solution techniques and existence-uniqueness questions; spectral theory of symmetric linear operators on Hilbert spaces and its connections with matrix diagonalization and boundary value problems; the theory of constrained minimization of functionals on a Banach space and its relation to optimal control and programming problems. Additional material if time permits. Physical motivation will be drawn from a variety of sources, historical and current, including the literature of theoretical mechanics, communication and control theory, and numerical analysis.

1150 Advanced Engineering Analysis I (u,g). Fall. Credit three hours. Prerequisite: Mathematics 294 or equivalent. Lectures, T Th S 11:15. Mr. Lance.

Includes topics in advanced calculus leading to methods of applied science, with emphasis on applications of importance in engineering. Mathematical topics include infinite series, uniform convergence, Fourier series, functions of several variables, vectors and vector fields, Cartesian tensors. Application to stress analysis, heat and fluid flow, and dynamics.

1151 Advanced Engineering Analysis II (u,g). Spring. Credit three hours. Prerequisite: 1150 or equivalent. Mr. Lance.
A continuation of 1150, including ordinary and partial differential equations, initial-value problems and boundary-value problems; analytical and numerical methods of solution. Applications to heat flow and diffusion, fluid flow, elastodynamics. At the level of *Engineering Analysis* by Crandall.

1180 Methods of Applied Mathematics I (g). Fall. Credit three hours. Lectures, M W F 11:15. Open to graduate students or to undergraduates with the consent of the instructor. Intended for students who plan to use applied mathematics frequently; many students will supplement it with 1181(–83). Mr. Burns.
Ordinary differential equations; series; orthogonal functions and Sturm-Liouville theory; functions of several real variables; vector fields and integral theorems; matrices; partial differential equations. Emphasis on applications and techniques of solution, wherever possible. At the level of *Mathematics of Physics and Modern Engineering* by Sokolnikoff and Redheffer.

1181 Methods of Applied Mathematics II (g). Spring. Credit three hours. Three lectures. Prerequisite: 1180 or the equivalent. Mr. Burns.
Continuation of partial differential equations; Green's function; Fourier and Laplace transforms; complex variables; calculus of variations; tensor analysis.

1182 Methods of Applied Mathematics III (g). Fall. Credit three hours. Lectures, M W 2:30–4. Prerequisite: 1181 or equivalent. Mr. Dunn.
Application of advanced mathematical techniques to engineering problems. Conformal mapping; complex integral calculus; Green's function; integral transforms; asymptotics, including steepest descent and stationary phase; Wiener-Hopf technique; general theory of characteristics; perturbation methods; singular perturbations, including PLK method and boundary layers. Problems drawn from vibrations and acoustics, fluid mechanics and elasticity, heat transfer, and electromagnetics.

1183 Methods of Applied Mathematics IV (g). Spring. Credit three hours. Three lectures. Prerequisite: 1182 or equivalent. Mr. Ludford.
More extensive treatment of 1182. Topics include: method of matched asymptotic expansions; WKB approximation; Hilbert-Schmidt and Fredholm theories of integral equations; singular integral equations; Wiener-Hopf equations with application to finite interval; Carleman equation and its generalization, effective approximations; further methods in partial differential equations, slot problems.

[**1184 Numerical Methods in Engineering (g).** Spring. Credit three hours. Prerequisite: 1181 or equivalent. Not offered in 1971–72.
Methods for obtaining numerical solutions to problems arising in engineering. Linear and nonlinear mechanical systems. Ordinary and partial differential equations, initial-value problems, boundary-value problems, eigenvalue problems, and extrema. Calculus of variations. Function-space methods. Applications to vibrations, diffusion, heat transfer, wave propagation, membranes, plates, fluid flow, and celestial mechanics. Simulation of dynamical systems. Analog computation.]

Mechanics of Solids

[**1210 Introduction to Continuum Mechanics (u,g).** Fall. Credit three hours. Three lectures. Not offered in 1971–72.
Introduction to the physical aspects of modern continuum mechanics, providing a foundation for further studies in fluid and solid mechanics, materials science, and other branches of engineering. Vectors and tensors. Analysis of stress and strain. Deformation. Constitutive equations. Balance principles and the derivation of field equations. Examples from fluid dynamics and elasticity.]

1263 Applied Elasticity (u,g). Fall. Credit three hours. Lectures, M W 1–2:15. Mr. Conway.
Analysis of thin curved bars. Plane stress and plane strain in the circular cylinder; effects of pressure, rotation and thermal stress. Small- and large-deflection theory of plates, classical and approximate methods. Strain-energy methods. Symmetrically loaded thin cylindrical shell. Torsion of thin-walled members. A first course in the mechanics of elastic deformable bodies with structural applications.

1264 Theory of Elasticity (g). Spring. Credit three hours. Three lectures. Mr. Conway.
General analysis of stress and strain. Plane stress and strain. Airy's stress function solutions using Fourier series, Fourier integral, and approximate methods. St. Venant and Mitchell torsion theory. Simple three-dimensional solutions. Bending of prismatical bars. Axially loaded circular cylinder and half space.

1265 Mathematical Theory of Elasticity (g). Spring. Credit three hours. Three lectures.
Development in tensor form of the basic equations of large-deformation elasticity; solution of certain large-deformation problems. Linearization to infinitesimal elasticity. Boussinesq-Papkovich potentials and their application to three-dimensional problems; contact problems; plane stress by method of Muskhelishvili; application of conformal mapping; Cauchy integral techniques in elasticity; torsion problems.

1267 Introduction to The Inelastic Behavior of Solids and Structures (u,g). Fall. Credit three hours. Lectures, T Th 11:15–12:30. Mr. Boley.
Introduction to the physical aspects of inelastic material behavior. Microscopic, macroscopic, and idealized models for elastic, plastic, viscous, viscoplastic, and locking materials. Mathematical formulations and methods of solution. Design concepts.

[**1268 Theory of Plasticity (u,g).** Spring. Credit three hours. Three lectures. Not offered in 1971–72.
Theory of inelastic behavior of materials. Plastic stress-strain laws, yield criteria, and flow laws. Flexure and torsion of bars; thick-walled cylinders; metal forming and extrusion; stress analysis in metals and soils. Limit analysis of beams, plates, and shells. Shake-down. Selected topics in dynamic plasticity.]

[**1269 Thermal Stresses (u,g).** Fall. Credit two hours. Not offered in 1971–72.
Behavior of solids and structures at elevated temperatures. Thermomechanical coupling, inertia effects. Review of heat conduction in solids. Thermoelastic behavior of beams, plates, and simple structures. Thermally induced vibrations. Elastic and inelastic stress analysis. Thermal buckling.]

[1270 **Energy Methods in Solid Mechanics (u,g).** Spring. Credit two hours. Not offered in 1971–72.
A study of the various energy methods used in structural analysis. Principle of virtual work. Strain energy and complementary energy theorems. General energy theorems. Reissner-Hellinger Principle. Applications to finite-element analyses. Reciprocal theorems. Elastic and inelastic analyses. Dynamical problems. Energy stability criteria.]

1280 Composite Materials (u,g). (Same as Materials Science and Engineering 6625.) Spring. Credit three hours. Three lectures. Staff: faculty from Materials Science and Engineering and Theoretical and Applied Mechanics; guest lecturers.
The physical basis of the strength, elastic modulus, and fracture resistance of composite materials; the micro- and macro-mechanics of composites, their mechanical response, and important composite systems including fabrication, processing, and design applications. Compatibility and interaction of fibers and matrix. Fatigue, creep, fracture mechanisms. Analysis of primary configurations such as tension and compression members, beams, and plates including such local effects as bonding, fiber-tip stress concentration, and buckling.

1290 Continuum Mechanics and Thermodynamics (u,g). Fall. Credit three hours. Three lectures. Mr. Jenkins.
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.

1291 Continuum Mechanics and Thermodynamics of Solids (g). Spring. Credit three hours. Three lectures. Prerequisite: 1290. Mr. Jenkins. Not offered in 1972–73.
Theory of (nonlinear) elasticity and thermoelasticity: universal solutions, wave propagation, stability theory. Nonlinear viscoelasticity and introduction to more general theories of solids.

[1292 **Continuum Mechanics and Thermodynamics of Fluids (g).** Spring. Credit three hours. Prerequisite: 1290. Not offered in 1971–72.
Viscometric flows of non-Newtonian fluids. Theory of mixtures. Oriented media and the theory of liquid crystals.]

Dynamics and Vibrations

1362 Vibration of Elastic Systems (u,g). Fall. Credit four hours. Lectures, T Th S 10:10–11; one laboratory.
Review of vibration of linear-lumped systems, with emphasis on matrix method and transient phenomena. Free and forced vibration of continuous systems, including strings, rods, beams, membranes, and plates. Waves in rods and beams. Orthogonality conditions and application of generalized functions. Rayleigh-Ritz method. Mathieu function and dynamic instability of strings, columns, and other elastic systems. Nonlinear phenomena.

1366 Stress Waves in Solids (g). Spring. Credit three hours. Three lectures. Mr. Robinson.
General equations of elastodynamics. Waves in extended elastic media. Reflection and refraction of waves. Surface waves and waves in layered media. Vibrations and waves in strings, rods, beams, and plates. Dispersion in mechanical waveguides. Transient loads. Scattering of elastic waves and dynamical stress concentration. Waves in anisotropic media and viscoelastic media.

1370 Intermediate Dynamics (g). Fall. Credit three hours. Lectures, T Th 1:10–2:25. For graduate students or advanced undergraduate students with consent of instructor. Mr. Ludford.
Newtonian mechanics for single particles and systems of particles, conservation laws, central-force motion; rigid-body mechanics, Euler's equations, tops, gyroscopes; generalized coordinates, introduction to Lagrangian mechanics, Hamilton's principle; small oscillations.

1371 Advanced Dynamics (g). Spring. Credit three hours. Prerequisite: 1370 or equivalent. Mr. Alfriend.
Hamilton's principle, Lagrangian mechanics, principle of least constraint, principle of least action, Gibbs-Appell equations; Hamilton's equations, canonical transformations, Hamilton-Jacobi theory; perturbation theory, von Zeipel method, method of Lie transforms, commensurability effects; quantum mechanics, special relativity. At the level of *A Treatise on Analytical Dynamics* by Pars.

[1375 **Nonlinear Vibrations (g).** Spring. Credit three hours. Three lectures. Prerequisite: 1362 or equivalent. Not offered in 1971–72.
Phase-plane techniques, singular points, conservative systems, limit cycles, Poincaré-Bendixson theorem, Poincaré's cycles without contact, method of isoclines, Lienard's method, Lyapunov Stability, Floquet theory, Hill's and Mathieu's equation, perturbation methods, method of Krylov and Bogoliubov. Emphasis on applications throughout.]

1376 Stability of Motion (g). Spring. Credit three hours. Three lectures. Mr. Rand.
Physical notions of stability, Lyapunov stability, orbital stability, Lyapunov's second method, validity of linearized variational equations, stability of equilibrium points, stability of periodic motions, Floquet theory, perturbations, structural stability, stability of motions governed by partial differential equations, Poisson stability, ergodicity.

[1381 **Dynamics of Flight (g).** Spring. Credit three hours. Two lectures. Prerequisite: 1181 and 1370, or equivalent. Not offered in 1971–72.
Introduction to the dynamics of atmospheric vehicles. Static stability and control. Derivation of the general equations of unsteady motion. Small disturbance equations. Dynamic stability. Dynamic response to controls. Stability augmentation and automatic control. Flight path optimization techniques. At the level of *Dynamics of Flight* by Etkin.]

Experimental Mechanics

1459 Experimental Mechanics (u,g). Fall. Credit three hours. T Th 2:30–4:25. Messrs. Robinson and Sachse.
The student is expected to perform four to six experiments selected to meet his individual interests. Available experiments include: elastic waves in rods, viscoelastic waves and internal damping, linear vibrations of beams and plates, nonlinear response of elastic plates; two- and three-dimensional photoelasticity; plastic response of structures; magnetoelastic buckling of a beam-plate; gyroscopic motion; linear oscillators and analog computers.

1460 Experimental Mechanics (u,g). Spring. Credit three hours. Messrs. Sachse and Robinson.
The student is expected to perform two to three "in-depth" experiments chosen from areas very active in contemporary experimental mechanics and re-

flecting some of the research interests of the faculty. At present, experiments utilizing holographic interferometry techniques and internal friction techniques are planned. The specific experiments to be performed are selected by the student to meet his individual interests.

Space Mechanics and Aerospace Structures

1730–1731 Transportation Structures (u,g). (Same as Civil and Environmental Engineering 2730–2731.) Fall and spring. Credit three hours. Lectures, T Th 1:10–2:25. To be offered in alternate years, beginning in 1971–72. Prerequisite: 1021. Messrs. Boley and Gallagher.
Treatment of structural design aspects of land, sea, and air vehicles. Description of applicable design specifications, design environments, materials failure criteria, forms of construction, and methods of structural analysis. Each student will be required to develop a term paper on a facet of the course.

1772 Space Flight Mechanics (u,g). Fall. Credit three hours. Lectures, T Th 11:15–12:30. Mr. Rand.
Gravitational potential of the earth; two-body problem; three-body problem; restricted three-body problem; Jacobi's integral; Hill curves; libration points and stability. Lagrange's planetary equations; effect of oblate earth, atmospheric drag, and solar radiation on satellite orbits; satellite attitude control; orbital transfer and orbital maneuvers; rendezvous problems.

[**1773 Mechanics of the Solar System (u,g).** Spring. Credit three hours. Three lectures. Prerequisite: 1370 or consent of instructor. Not offered in 1971–72.
Application of the principles of mechanics (of dynamics principally, with some attention to elasticity) to explain some large-scale physical phenomena in the solar system. An understanding of the interplanetary environment should also be developed during the course. The topics covered will include: seismic waves and the free oscillations of the earth; gravitational potential of planets and their rotation; tidal interactions and Roche's limit; dynamics of the earth-moon system; spin-orbit coupling for Mercury and Venus; dynamics of comets, interplanetary dust, and energetic charged particles; perihelion precession of Mercury; theories of the origin of the solar system.]

[**1774 Trajectory Optimization (g).** Spring. Credit three hours. Three lectures. Prerequisite: 1772 or consent of instructor. Not offered in 1971–72.
Review of calculus of variations. Optimal impulsive trajectories. Maximum principle, bounded controls, singular arcs, and bounded-state variables. Numerical methods, gradient techniques, quasilinearization. Applications to minimum-time and minimum-fuel orbit transfer; rendezvous and interplanetary trajectories.]

Biomechanics

1801 Introduction to Biomechanics, Bioengineering, Bionics, and Robots (u,g). Fall. Credit three hours. Lectures, M W F 2:30. Prerequisite: elementary differential equations, linear algebra, and probability; or consent of the instructor. An introduction to 1892, but not necessarily a prerequisite. Mr. Block.
A lecture course intended primarily for undergraduates. Bionics, the general subject, is the study of possible applications to the design of engineering devices of techniques used by living organisms. Examples are how birds fly, fish swim, and men run; and how animals see, hear, learn, recognize, recall, guess, and reason. The possibility of designing robots to operate in ways analogous to physiological and mental functions will be explored. Among topics to be considered are: artificial intelligence, pattern recognition, neural network and brain models, philosophical questions of computers and the foundations of mathematics, theoretical aspects of competitive and evolutionary ecological systems, developments in biomedical engineering, and progress in the augmentation of human muscular and mental power. Students interested in particular areas may do individual or team work consisting of study, research, design, or construction.

1892 Current Research Problems in Bionics and Robots (u,g). Spring. One to four credit hours, as arranged in prior consultation with the staff. Course 1801 is introductory, but not necessarily a prerequisite. Messrs. Block, Dunn, Rand, and staff.
A graduate-level seminar, concentrating on a few of the topics listed under 1801. Faculty and students will report on current research articles, papers, books, and personal investigations in such areas as: robots designed to learn natural language; artificial intelligence; pattern recognition and scene analysis by machine; adaptive control; and brain and behavior models.

Special Courses

1904–1905 Seminar in Fluid Mechanics (g). Fall and spring. Credit three hours. Prerequisite: consent of the instructor. Mr. Ludford.
Study and discussion of topics of current research interest in the field of fluid mechanics. Participants prepare and deliver reports based on published and unpublished literature.

1921–1922 Project in Mechanics (g). Fall and spring. Credit to be arranged.
A minimum of three credit hours must be completed by each candidate for the Master of Engineering (Engineering Mechanics) degree.

1996 Research in Theoretical and Applied Mechanics (g). Either term. Credit as arranged.
Thesis, literature survey, or independent research on a subject of theoretical and applied mechanics. This research will be under the guidance of a staff member.

1997 Selected Topics in Theoretical and Applied Mechanics (g). Either term. Credit as arranged.
Special lectures or seminars on subjects of current interest in the Field of Theoretical and Applied Mechanics. Topics will be announced when the course is offered.

Thermal Engineering

See p. 94.

Courses of Interest to Students from Other Schools and Colleges in the University

201 (Computer Science) Survey of Computer Science (u). Fall. Credit three hours. M W F 9:05.
Introduction to the structure and use of the modern computer. Intended to be an overview of the material; emphasis is on nonnumeric computer appli-

cations, such as information retrieval, language processing, and artificial intelligence. A limited introduction to programming in a problem-oriented language is included.

202 (Computer Science) Computers and Programming (u). Either term. Credit three hours. Prerequisite: 201 or some programming experience in an algebraic language. M W 9:05 or T Th 10:10; laboratory M T W Th or F 2:30–4:25.
Intended as a foundations course in computer programming and machine organization. Algorithms and their relation to computers and programs. A procedure-oriented language: specification of syntax and semantics, data types and structure, statement types, program structure. Machine organization: components, representation of data, storage addressing, instructions, interpretation cycle, interrupts. Some assembly language programming. Programming and debugging problems on a computer are essential parts of this course.

205 (University Program on Science, Technology, and Society) Social Implications of Technology (u,g). Fall. Credit three hours. (S/U or letter grade). One lecture, one discussion. M 7:30–9:00 p.m.; the time for the discussion section will be arranged. The course is open to all Cornell students beyond the freshman year. Mr. Nelkin.
Discussion of some of the issues pertaining to the development, implementation, and assessment of technology. Emphasis will be on the social, political, and economic aspects of current problems having an important technological component. Technical background will be developed to the extent required for an intelligent consideration of policy alternatives.

305 (Computer Science) The Computerized Society (u). Fall Term. Credit three hours. T Th 10:10.
A seminar-style course designed to bring the perspectives of the sciences, social sciences, and humanities to the question of the impact of computers on society. Enrollment will be limited to thirty students of varied backgrounds who show an interest in the present-day influences of computers on human life and the future alternatives in the application of computers to society. Topics to be discussed include: the potentialities and limitations of the computer—the popular view *versus* the computer scientist's view; man and the machine—the identity crisis; human privacy and the national data banks; human decision making *versus* military and industrial automation; the knowledge explosion and information-retrieval systems; technological and occupational obsolescence—what price for progress?; social structure in the year 2000.

2605 (Civil and Environmental Engineering) The Law and Environmental Control (g). Fall. Credit three hours. Prerequisite: permission of the instructor. Designed for seniors and graduate students. Mr. Bereano.
An introduction to the structure and operation of the legal system and an investigation of the manner in which that system may handle environmental problems. The interaction of law and science; regional problems and political jurisdictional boundaries; the police power of the states; statutory law and case law; the judicial function; the nature and functions of the administrative agencies; environmental regulation; recent environmental case law; the interstate compact.

2606 (Civil and Environmental Engineering) Seminar in Technology Assessment (u,g). Spring. Credit three hours. Mr. Bereano and others.
An interdisciplinary seminar dealing with the social consequences of future technological development and the means by which technology can be guided in socially beneficial directions. Student-faculty task forces will organize to undertake projects exploring aspects of technology assessment theory and methodology, perform simple assessments, or investigate questions pertaining to the design and functioning of institutions to perform such tasks.

2611–2612 (Civil and Environmental Engineering) Microeconomic Theory I and II (u,g). Fall and spring. Credit four hours each term. Prerequisite: permission of the instructor. Mr. Falkson.
Topics include the scope and method of economics, individual and market demand, competitive equilibrium, monopoly, price discrimination, application of price theory to public policy, minimum wage laws, labor unions, the linear programming approach to the theory of production, systems analysis of public projects, the theory of imperfect competition, game theory, monopolistic and spatial competition, consumer behavior, utility theories, welfare economics, materials balance and recycling. See p. 67 for a more complete description.

[**2613 (Civil and Environmental Engineering) Macroeconomic Theory (u,g).** Credit four hours. Prerequisite: 2611, 2612. Mr. Falkson. Not offered in 1971–72.
Topics include national income accounting, money and banking, Federal Reserve policy, classical model of employment, inflation, Keynesian model of income determination, theories of consumption and investment, fiscal policy, foreign trade, dynamic macro models, accelerator-multiplier interaction, Harod-Domar growth model, neoclassical growth models, population growth, regional development models.]

1801 (Theoretical and Applied Mechanics) Introduction to Biomechanics, Bioengineering, Bionics, and Robots (u,g). Fall. Credit three hours. Lectures, M W F 2:30. Prerequisite: elementary differential equations, linear algebra, and probability; or consent of the instructor. Mr. Block.
A lecture course intended primarily for undergraduates. Bionics, the general subject, is the study of possible applications to the design of engineering devices of techniques used by living organisms. Examples are how birds fly, fish swim, and men run; and how animals see, hear, learn, recognize, recall, guess, and reason. The possibility of designing robots to operate in ways analogous to physiological and mental functions will be explored. Among topics to be considered are: artificial intelligence, pattern recognition, neural network and brain models, philosophical questions of computers and the foundations of mathematics, theoretical aspects of competitive and evolutionary ecological systems, developments in biomedical engineering, and progress in the augmentation of human muscular and mental power. Students interested in particular areas may do individual or team work consisting of study, research, design, or construction.

3020 (Mechanical Engineering) The Age of Power—A History of Technology (u). Spring. Credit three hours. Three lecture-discussions. Mr. Conta.
A history of technology traced from its origin before the dawn of history and ending with modern industrial society. Emphasis will be upon the nineteenth and twentieth centuries and what has been called the second revolution in power—the vast increase in available power made possible by the development of the Watt steam engine and the exploitation of the thermal energy of wood and the fos-

sil fuels. The relationship of this technology to other technologies and to the economic, social, and political developments of the period.

3659 (Mechanical Engineering) The Nature of Thermodynamics (u,g). Fall. Credit three hours. Three recitations. Prerequisite: a course in thermodynamics or permission of the instructor. Mr. Conta.
A study of the history, philosophy, and mathematics of thermodynamics with emphasis on its scope and limitations. A study of the methods of exposition of the concepts and laws of thermodynamics; a comparison of the intuitive, the axiomatic, and the statistical approaches. The course will be principle rather than problem oriented, and each student will be expected to develop a special topic in thermodynamics, present it orally, and write a term paper in place of a final examination.

4110 (Electrical Engineering) Computer Application (u). Either term. Credit three hours. Two lectures, one laboratory.
Organization and structure of the digital computer with particular reference to the contribution of modern technology to computer development. The digital computer will be separated into its basic units and the function of these units alone and in total will be investigated. Tools employed in this investigation will be a mechanical simulator of a digital computer (Digi-Comp II) and a logic board consisting of switches and relays. Work with machine language and the development of "software" will lead into programming languages and their application. Without emphasizing program techniques, the course should, nevertheless, provide a cure for "digi-comphobia" (the irrational fear of digital computers). No technical background beyond high school mathematics is required. At the level of *The Man-Made World* by the Engineering Concepts Curriculum Project Committee.

[4435 (Electrical Engineering) Electronics and Music (u,g). Fall. Credit three hours. Electrical engineering students may take the course as a free elective. Not offered in 1971–72.
An introduction to musical acoustics and the application of electronics to production as well as reproduction of musical material. Topics include physical properties of sound, historical development of musical materials, physical properties of musical instruments, speech and hearing mechanisms, electronic terms and concepts, elements of sound reproducing chains, home and professional audio practices, electronic musical instruments, and electronic music composition processes. Outside work will include independent reading and writing of papers on selected topics.]

[5061 (Chemical Engineering) Seminar on the Engineer and Society (u,g). Fall. Credit one hour. Not offered in 1971–72.
Review of major social changes caused by science and technology; discussion of current social challenges to the engineer, with particular emphasis on the chemical process industry.]

7003 (Aerospace Engineering) Introduction to Geophysics (u,g). Fall. Credit three hours. Open to upperclass engineers, majors in the physical sciences, and others by permission of the instructor. Mr. Turcotte.
Rotation and figure of the earth, gravitational field, seismology, geomagnetism, creep and anelasticity, radioactivity, Earth's internal heat, continental drift, and mantle convection. Text: *Physics of the Earth* by F. D. Stacey.

8301 (Applied and Engineering Physics) Nuclear Energy and the Environment (u). Fall. Credit three hours. Two lectures and one two-hour recitation or laboratory per week. The level of presentation assumes knowledge of introductory physics, chemistry, and calculus, but previous knowledge of biology is not required. It is suitable as an elective for sophomore, junior, and senior engineering students and also for science majors in other colleges. Messrs. Kostroun, Cady, and Clark.
Fundamentals of nuclear radiations and their measurement and interaction with matter, the natural radiation environment, and sources of man-made radioactivity (five weeks); radiation chemistry, radiation biology, somatic and genetic effects of nuclear radiation, movement of radioactive materials in the biosphere, and bases of radiation protection standards (five weeks); environmental effects of nuclear electricity generation and nuclear fuel mining, processing, and waste storage, control of radiation hazards, and waste heat problems (four weeks).

8901 (Applied and Engineering Physics) Issues and Methods in Applying Science (g). Fall. Credit three hours. For graduate students, and upperclass undergraduates with consent of the instructor. Mr. Webb.
This course is designed to offer graduate students majoring in the physical sciences, engineering, business, or social science an introduction to the issues, methods, and problems involved in the application of physical science in "mission-oriented" research, development, industrial technology, and engineering and in technological problems of contemporary society. Presentation is in seminar style, with visiting lecturers, discussion sessions, and case studies. A detailed syllabus may be obtained from Mr. Webb, 237 Clark Hall.

Faculty and Staff

University Administration

Dale R. Corson, President of the University
Robert A. Plane, University Provost
W. Donald Cooke, Vice President for Research
Lewis H. Durland, University Treasurer
William D. Gurowitz, Vice President for Campus Affairs
W. Keith Kennedy, Vice Provost
Samuel A. Lawrence, Vice President for Administration
E. Hugh Luckey, Vice President for Medical Affairs
Thomas W. Mackesey, Vice President for Planning
Paul L. McKeegan, Director of the Budget
Arthur H. Peterson, University Controller
Richard M. Ramin, Vice President for Public Affairs
Neal R. Stamp, Secretary of the Corporation and University Counsel

Faculty and Staff of the College of Engineering

Andrew Schultz, Jr., B.S., Ph.D., P.E., Dean; Professor of Industrial Engineering and Operations Research
Malcolm S. Burton, B.S., S.M., Associate Dean; Professor of Materials Science and Engineering
Edmund T. Cranch, B.M.E., Ph.D., Associate Dean; Professor of Theoretical and Applied Mechanics
John F. McManus, C.E., Associate Dean
Donald F. Berth, B.S.Ch.E., M.S.Ch.E., Assistant Dean; Lecturer in Engineering
Carson Carr, Jr., B.S., M.A., Director of Student Personnel
Donald G. Dickason, A.B., M.Ed., Director of Engineering Admissions
Robert E. Gardner, B.A., Ph.D., Assistant to the Dean; Lecturer in Engineering
Donald B. Gordon, B.S.A.E., M.A., Director of Industrial Liaison
Richard L. Jewitt, B.S., M.S., P.E., Assistant Director of Continuing Education; Assistant to the Director of Mechanical Engineering
David C. Johnson, A.B., Assistant Director of Engineering Admissions
Gladys J. McConkey, B.S., M.S., Editor, College of Engineering Publications
Jeanette Wood, B.S., Librarian, College of Engineering Library

Emeritus Professors

Thomas J. Baird, B.Arch., M.R.P., Professor of Machine Design, Emeritus
Lawrence Adams Burckmeyer, Jr., B.S., E.E., Professor of Electrical Engineering, Emeritus
Nephi Albert Christensen, B.S., B.S.C.E., M.S.C.E., Ph.D., P.E., Professor of Civil Engineering, Emeritus
George B. DuBois, A.B., M.E., P.E., Professor of Mechanical Engineering, Emeritus
John C. Gebhard, C.E., P.E., Professor of Civil Engineering, Emeritus
Roger L. Geer, M.E., Professor of Mechanical Engineering, Emeritus
James Lawrence Gregg, B.E., P.E., Professor of Materials Science and Engineering, Emeritus
George Raymond Hanselman, M.E., M.S., P.E., Professor of Mechanical Engineering, Emeritus
Solomon Cady Hollister, B.S., C.E., D.Eng., Sc.D., Professor of Civil Engineering, Emeritus
Eric V. Howell, C.E., Professor of Mechanics, Emeritus
Clyde E. Ingalls, E.E., P.E., Professor of Electrical Engineering, Emeritus
Joseph O. Jeffrey, M.E., M.M.E., Professor of Materials Science and Engineering, Emeritus
Michel George Malti, A.B., B.S., M.E.E., Ph.D., Professor of Electrical Engineering, Emeritus
Clyde Walter Mason, A.B., Ph.D., Professor of Chemical Engineering, Emeritus
True McLean, E.E., P.E., Professor of Electrical Engineering, Emeritus
Wilbur E. Meserve, B.S., M.S., M.E.E., Ph.D., P.E., Professor of Electrical Engineering, Emeritus
John R. Moynihan, M.E., M.M.E., P.E., Professor of Theoretical and Applied Mechanics, Emeritus
Harold C. Perkins, M.E., Professor of Mechanics, Emeritus
John Edwin Perry, B.S., Professor of Railroad Engineering, Emeritus
Fred Hoffman Rhodes, A.B., Ph.D., Professor of Chemical Engineering, Emeritus
Herbert Henry Scofield, M.E., Professor of Testing Materials, Emeritus
Robert Hermann Siegfried, M.E., Professor of Mechanical Engineering, Emeritus
Everett Milton Strong, B.S., P.E., Professor of Electrical Engineering, Emeritus
Charles Leopold Walker, C.E., Professor of Sanitary Engineering, Emeritus

Visiting Professors

B. S. Borie, B.S., Ph.D., Visiting Professor of Materials Science and Engineering
C. Roger Glassey, B.M.E., C.I.A., M.S., Ph.D., Visiting Associate Professor of Environmental Engineering

and of Operations Research
Ardeshir Jahanshahi, B.Sc., M.S., Ph.D., Visiting Professor of Theoretical and Applied Mechanics
James T. Jenkins, B.S., Ph.D., Visiting Assistant Professor of Theoretical and Applied Mechanics

Faculty

Kyle T. Alfriend, B.S., M.S., Ph.D., Assistant Professor of Theoretical and Applied Mechanics
Robert N. Allen, B.S.(A.E.-M.E.), Associate Professor of Industrial Engineering and Operations Research; Director of the Engineering Cooperative Program
John L. Anderson, B.Ch.E., M.S., Ph.D., Assistant Professor of Chemical Engineering
Paul D. Ankrum, B.S.E.E., A.B., M.S., in Eng'g., Professor of Electrical Engineering
Deiter G. Ast, Dipl. Phys., Ph.D., Assistant Professor of Materials Science and Engineering
Peter L. Auer, A.B., Ph.D., Professor of Aerospace Engineering; Director of the Laboratory for Plasma Studies
Joseph M. Ballantyne, B.S., B.S.E.E., S.M., Ph.D., Associate Professor of Electrical Engineering
Robert W. Balluffi, Sc.B., Sc.D., Francis Norwood Bard Professor of Materials Science and Engineering
Donald L. Bartel, B.S., M.S., Ph.D., Assistant Professor of Mechanical Engineering
Boris W. Batterman, S.B., Ph.D., Professor of Materials Science and Engineering and of Applied Physics (on leave, academic year 1971–72)
Robert E. Bechhofer, A.B., Ph.D., Professor of Operations Research; Chairman of the Department
Vaughn C. Behn, B.S., M.S., Dr.Eng., P.E., Associate Professor of Environmental Engineering
Donald J. Belcher, B.S.C.E., M.E., M.S., C.E., P.E., Professor of Environmental Engineering
Phillip L. Bereano, B.Ch.E., J.D., M.R.P., Assistant Professor of Environmental Engineering
Toby Berger, B.E., M.S., Ph.D., Assistant Professor of Electrical Engineering
Donald F. Berth, B.S.Ch.E., M.S.Ch.E., Lecturer in Engineering; Assistant Dean of the College
Louis J. Billera, B.S., M.A., Ph.D., Assistant Professor of Operations Research
Kenneth B. Bischoff, B.S., Ph.D., P.E., Walter R. Read Professor of Engineering; Professor of Chemical Engineering; Director of the School of Chemical Engineering
Richard D. Black, B.S., M.S., Ph.D., Associate Professor of Agricultural Engineering
John M. Blakely, B.Sc., Ph.D., Associate Professor of Materials Science and Engineering
Henry D. Block, B.S., B.C.E., M.S., Ph.D., Professor of Applied Mathematics
Bruno A. Boley, B.C.E., M.Ae.E., Sc.D., Joseph P. Ripley Professor of Engineering; Professor of Theoretical and Applied Mechanics; Chairman of the Department
Ralph Bolgiano, Jr., B.S., B.E.E., M.E.E., Ph.D., Professor of Electrical Engineering (on leave, academic year 1971–72)
John F. Booker, B.E., M.A.E., Ph.D., Associate Professor of Mechanical Engineering
Walter H. Bray, B.C.E., M.S., Engr., Ph.D., Assistant Professor of Engineering
Neil M. Brice, B.S., M.S., Ph.D., Associate Professor of Electrical Engineering
Mark Brown, B.S., M.S., Ph.D., Assistant Professor of Operations Research
Wilfried Brutsaert, Engr., M.S., Ph.D., Associate Professor of Environmental Engineering; Representative of the Graduate Field of Civil and Environmental Engineering
Nelson H. Bryant, E.E., M.E.E., Associate Professor of Electrical Engineering
James R. Bunch, B.S., M.A., Ph.D., Assistant Professor of Computer Science
Joseph A. Burns, B.S., Ph.D., Assistant Professor of Theoretical and Applied Mechanics
Arthur H. Burr, B.S., M.S., Ph.D., Hiram Sibley Professor of Mechanical Engineering
Malcolm S. Burton, B.S., S.M., Professor of Materials Science and Engineering; Associate Dean of the College
K. Bingham Cady, S.B., Ph.D., Associate Professor of Applied Physics
Robert R. Capranica, B.S., M.S., Sc.D., Associate Professor of Electrical Engineering and a member of the Division of Biological Sciences
Herbert J. Carlin, B.S., M.S., D.E.E., J. Preston Levis Professor of Engineering; Professor of Electrical Engineering; Director of the School
David D. Clark, A.B., Ph.D., Professor of Applied Physics; Director of the Ward Laboratory of Nuclear Engineering
Roderick K. Clayton, B.S., Ph.D., Professor of Applied Physics and of Biology and Biophysics
George G. Cocks, B.S., Ph.D., Associate Professor of Chemical Engineering (on leave, spring term 1972)
Robert L. Constable, B.A., M.A., Ph.D., Assistant Professor of Computer Science
Bartholomew J. Conta, B.S., M.S., Professor of Mechanical Engineering
Harry D. Conway, B.Sc., Ph.D., M.A., D.Sc., Professor of Theoretical and Applied Mechanics
Richard W. Conway, B.M.E., Ph.D., Professor of Operations Research and of Computer Science
J. Robert Cooke, B.S., M.S., Ph.D., Associate Professor of Agricultural Engineering
Terrill A. Cool, B.S., M.S., Ph.D., Associate Professor of Thermal Engineering (on leave, academic year 1971–72)
Dale R. Corson, A.B., A.M., Ph.D., Professor of Applied Physics and of Physics; President of the University
Edmund T. Cranch, B.M.E., Ph.D., Professor of Theoretical and Applied Mechanics and of Mechanical Engineering; Associate Dean of the College
Trevor R. Cuykendall, B.Sc., M.Sc., Ph.D., Spencer T. Olin Professor of Engineering; Professor of Engineering Physics and of Applied Physics
G. Conrad Dalman, B.E.E., M.E.E., D.E.E., Professor of Electrical Engineering
P. C. Tobias de Boer, Jr., Mech.Eng., Ph.D., Associate Professor of Aerospace Engineering (on leave, academic year 1971–72)
John E. Dennis, Jr., B.S., M.S., Ph.D., Associate Professor of Computer Science
David Dropkin, M.E., M.M.E., Ph.D., John Edson Sweet Professor of Mechanical Engineering; Representative of the Graduate Field
Joseph C. Dunn, B.Aero.E., M.S., Ph.D., Assistant Professor of Theoretical and Applied Mechanics
Leonard B. Dworsky, B.S., M.A., Professor of Environmental Engineering; Director of the Water Resources and Marine Sciences Center
Lester F. Eastman, B.E.E., M.S., Ph.D., Professor of Electrical Engineering (on leave, academic year 1971–72)
Victor H. Edwards, B.A., Ph.D., Assistant Professor of Chemical Engineering (on leave, fall term 1971–72)
Mark J. Eisner, B.A., Ph.D., Assistant Professor of Operations Research

Hamilton Emmons, A.B., M.S., (Applied Math.), M.S., (E.E.), Ph.D., Assistant Professor of Operations Research
William H. Erickson, B.S., M.S., P.E., Professor of Electrical Engineering (on leave, academic year 1971–72)
Howard N. Fairchild, M.E., E.E., P.E., Professor of Mechanical Engineering
Louis M. Falkson, A.B., M.A., Assistant Professor of Environmental Systems Engineering
Donald T. Farley, Jr., B.E.P., Ph.D., Professor of Electrical Engineering; Representative of the Graduate Field
Terrence L. Fine, B.E.E., S.M., Ph.D., Associate Professor of Electrical Engineering
Robert K. Finn, B.Chem., Ch.E., Ph.D., Professor of Chemical Engineering
Gordon P. Fisher, B.E., D.Eng., P.E., Professor of Environmental Engineering
Hans H. Fleischmann, Dipl.Phys., Dr.rer.nat., Associate Professor of Applied Physics
Orval C. French, B.S., M.S., Professor of Agricultural Engineering; Head of the Department
Jeffrey Frey, B.S., M.S., Ph.D., Assistant Professor of Electrical Engineering
D. Ray Fulkerson, B.A., M.S., Ph.D., Maxwell M. Upson Professor of Engineering; Professor of Operations Research
Ronald B. Furry, B.S., M.S., Ph.D., Associate Professor of Agricultural Engineering; Representative of the Graduate Field
Richard H. Gallagher, B.C.E., M.C.E., Ph.D., P.E., Professor of Structural Engineering; Chairman of the Department
Charles D. Gates, B.A., M.S., Professor of Environmental Engineering; Representative of the Graduate Field of Water Resources
Benjamin Gebhart, B.S.E., M.S.E., Ph.D., Professor of Mechanical Engineering
Albert R. George, B.S.E., M.A., Ph.D., Associate Professor of Aerospace Engineering (on leave, academic year 1971–72)
Peter Gergely, B.Eng., M.S., Ph.D., P.E., Associate Professor of Structural Engineering
Thomas Gold, B.A., M.A., Professor of Electrical Engineering and of Astronomy
Henry P. Goode, B.S., M.S., P.E., Professor of Industrial Engineering and Operations Research
Frederick C. Gouldin, B.S.E., M.A., Ph.D., Assistant Professor of Thermal Engineering
David Gries, B.S., M.S., Ph.D., Associate Professor of Computer Science; Representative of the Graduate Field
Wesley W. Gunkel, B.S., M.S., Ph.D., Professor of Agricultural Engineering
Douglas A. Haith, B.S., M.S., Ph.D., Assistant Professor of Agricultural Engineering and of Environmental Engineering
Peter Harriott, B.Chem.E., Sc.D., Professor of Chemical Engineering
Paul L. Hartman, B.S., Ph.D., Professor of Applied Physics and of Physics; Associate Director of the School of Applied and Engineering Physics
Juris Hartmanis, Cand.Phil., M.A., Ph.D., Professor of Computer Science (on leave, academic year 1971–72)
J. Eldred Hedrick, B.A., M.S., Ph.D., P.E., Professor of Chemical Engineering
William L. Hewitt, A.B., B.C.E., M.C.E., P.E., Associate Professor of Agricultural Engineering and of Environmental Engineering; Assistant Director of the School of Civil and Environmental Engineering
Paul S. Ho, B.S., M.S., Ph.D., Assistant Professor of Materials Science and Engineering
John E. Hopcroft, B.S., M.S., Ph.D., Associate Professor of Computer Science
Ellis Horowitz, B.S., M.S., Ph.D., Assistant Professor of Computer Science
Frederick Jelinek, B.S., M.S., Ph.D., Associate Professor of Electrical Engineering
Herbert H. Johnson, B.S., M.S., Ph.D., Professor of Materials Science and Engineering; Director of the Department
Myunghwan Kim, B.S., M.E., Ph.D., Associate Professor of Electrical Engineering
Vaclav O. Kostroun, B.S., M.S., Ph.D., Assistant Professor of Applied Physics
Edward J. Kramer, B.Ch.E., Ph.D., Assistant Professor of Materials Science and Engineering; Representative of the Graduate Field
Allan I. Krauter, M.E., M.S., Ph.D., Assistant Professor of Mechanical Engineering
James A. Krumhansl, B.S., M.S., Ph.D., Professor of Applied Physics and of Physics
Walter H. Ku, B.S., M.S., Ph.D., Associate Professor of Electrical Engineering
Arthur F. Kuckes, B.S., Ph.D., Professor of Applied Physics
Richard H. Lance, B.S., M.S., Ph.D., Associate Professor of Theoretical and Applied Mechanics
Alonzo Wm. Lawrence, B.S., M.S., Ph.D., Assistant Professor of Environmental Engineering
Charles A. Lee, B.E.E., Ph.D., Associate Professor of Electrical Engineering
Sidney Leibovich, B.S., Ph.D., Associate Professor of Thermal Engineering
Gilbert Levine, B.S., Ph.D., Professor of Agricultural Engineering
Che-Yu Li, B.Sc., Ph.D., Associate Professor of Materials Science and Engineering
Ta Liang, B. Eng., M.C.E., Ph.D., Professor of Environmental Engineering
Richard L. Liboff, A.B., Ph.D., Professor of Electrical Engineering and of Applied Physics (on leave, academic year 1971–72)
James A. Liggett, B.S., M.S., Ph.D., Associate Professor of Environmental Engineering
Simpson Linke, B.S.E.E., M.E.E., Professor of Electrical Engineering (on leave, academic year 1971–72)
Raymond C. Loehr, B.S., M.S., Ph.D., Professor of Agricultural Engineering and of Environmental Engineering
Howard A. Longhouse, B.S., M.S., Lecturer in Agricultural Engineering
Robert T. Lorenzen, B.S.A.E., B.S.C.E., M.S., P.E., Associate Professor of Agricultural Engineering
Daniel P. Loucks, B.S., M.S., Ph.D., Associate Professor of Environmental Engineering
William F. Lucas, B.S., M.A., M.S., Ph.D., Professor of Operations Research and of Applied Mathematics; Director of the Center for Applied Mathematics
Geoffrey S. S. Ludford, B.A., M.A., Ph.D., Sc.D., Professor of Applied Mathematics
David C. Ludington, B.S., M.S., Ph.D., Associate Professor of Agricultural Engineering
Walter R. Lynn, B.S., M.S., Ph.D., Professor of Environmental Engineering; Director of the School of Civil and Environmental Engineering
George B. Lyon, B.S., M.S., P.E., Associate Professor of Environmental Engineering; Secretary of the College of Engineering faculty
William L. Maxwell, B.M.E., Ph.D., Professor of Operations Research; Representative of the Graduate Field
Ross A. McFarlane, B.S., M.S., Ph.D., Associate Professor of Electrical Engineering

Henry S. McGaughan, B.S.E. (Physics), M.E.E., Professor of Electrical Engineering
William McGuire, B.S.C.E., M.C.E., P.E., Professor of Structural Engineering
Paul R. McIsaac, B.E.E., M.S.E., Ph.D., Professor of Electrical Engineering
Howard N. McManus, Jr., B.S.M.E., M.S., Ph.D., Professor of Mechanical Engineering; Chairman of the Department of Mechanical Systems and Design
Arthur J. McNair, B.S.(C.E.), M.S., C.E., P.E., Professor of Environmental Engineering
Ross McPherson, B.Sc., M.Sc., Ph.D., Assistant Professor of Applied Physics
Arnim H. Meyburg, B.A., M.S., Ph.D., Assistant Professor of Environmental Engineering
William F. Millier, B.S., Ph.D., Professor of Agricultural Engineering
Franklin K. Moore, B.S., Ph.D., Joseph C. Ford Professor of Mechanical Engineering; Chairman of the Department of Thermal Engineering
Jorge J. More, B.S., M.S., Ph.D., Assistant Professor of Computer Science
Howard L. Morgan, B.S., Ph.D., Assistant Professor of Operations Research and of Computer Science (on leave, academic year 1971–72)
John A. Nation, B.Sc., Ph.D., Assistant Professor of Electrical Engineering
Mark S. Nelkin, B.Sc., Ph.D., Professor of Applied Physics
George L. Nemhauser, B.Ch.E., M.S., Ph.D., Professor of Operations Research
Benjamin Nichols, B.E.E., M.E.E., Ph.D., Professor of Electrical Engineering (on leave, academic year 1971–72)
Arthur H. Nilson, B.S., M.S., Ph.D., P.E., Professor of Structural Engineering
Sidney Oldberg, M.E., Professor of Mechanical Engineering
Jack E. Oliver, B.A., M.A., Ph.D., Irving Porter Church Professor of Engineering; Chairman of the Department of Geological Sciences
Robert E. Osborn, B.S.E.E., P.E., Professor of Electrical Engineering
Edward Ott, B.E.E., M.S., Ph.D., Assistant Professor of Electrical Engineering (on leave, academic year 1971–72)
Charles K. Paul, B.S., M.S., Ph.D., Assistant Professor of Engineering
Yih-Hsing Pao, B.S., M.S., Ph.D., Professor of Theoretical and Applied Mechanics; Representative of the Graduate Field (on leave, academic year 1971–72)
Teoman Peköz, B.S., M.S., Ph.D., Assistant Professor of Structural Engineering
Richard M. Phelan, B.S.M.E., M.M.E., Professor of Mechanical Engineering
Christopher Pottle, B.Eng., M.S., Ph.D., Associate Professor of Electrical Engineering and of Computer Science
Narahari U. Prabhu, B.A., M.A., M.Sc., Professor of Operations Research
Richard H. Rand, B.E., M.S., Engr.Sc.D., Assistant Professor of Theoretical and Applied Mechanics
Gerald E. Rehkugler, B.S., M.S., Ph.D., P.E., Associate Professor of Agricultural Engineering
Edwin L. Resler, Jr., B.S.Aero.E., Ph.D., Joseph Newton Pew Jr. Professor of Engineering; Professor of Aerospace Engineering, of Electrical Engineering, and of Applied Physics; Director of the Graduate School of Aerospace Engineering
Thor N. Rhodin, B.S., A.M., Ph.D., Professor of Applied Physics
David N. Robinson, B.Sc., M.Sc., Ph.D., Assistant Professor of Theoretical and Applied Mechanics
Ferdinand Rodriguez, B.S., M.S., Ph.D., Associate Professor of Chemical Engineering (on leave, fall term 1971–72)
Joseph L. Rosson, B.S.E.E., M.E.E., Professor of Electrical Engineering; Assistant Director of the School
Norman Rostoker, B.A.Sc., M.A., Sc.D., IBM Professor of Engineering; Professor of Applied Physics
Arthur L. Ruoff, B.S., Ph.D., Professor of Materials Science and Engineering
Wolfgang H. Sachse, B.S., M.S.E., Ph.D., Assistant Professor of Theoretical and Applied Mechanics
Henri S. Sack, Dipl., Dr.Sc., Walter S. Carpenter Jr. Professor of Engineering; Professor of Applied Physics
Miriam M. Salpeter, B.A., M.A., Ph.D., Associate Professor of Applied Physics and of Neurobiology and Behavior
Gerard Salton, A.B., M.A., Ph.D., Professor of Computer Science; Chairman of the Department
Martin W. Sampson, B.S., M.S., Associate Professor of Industrial Engineering and Operations Research; Head of the Division of Unclassified Students; Dean of the Division of Summer Session and Extramural Courses
Dwight A. Sangrey, B.S., M.S., Ph.D., Associate Professor of Environmental Engineering
Stephen L. Sass, B.Ch.E., Ph.D., Assistant Professor of Materials Science and Engineering
Byron W. Saunders, B.S., M.S., Professor of Industrial Engineering and Operations Research; Director of the School
Eraldus N. Scala, B.S., M.S., D.Eng., Professor of Materials Science and Engineering
George F. Scheele, B.S.E., M.S., Ph.D., Associate Professor of Chemical Engineering; Representative of the Graduate Field
Andrew Schultz, Jr., B.S., Ph.D., P.E., Professor of Industrial Engineering and Operations Research; Dean of the College
Norman R. Scott, B.S.A.E., Ph.D., Associate Professor of Agricultural Engineering
William R. Sears, B.Aero.E., Ph.D., John LaPorte Given Professor of Engineering; Professor of Aerospace Engineering
A. Richard Seebass, B.S.E., M.S.E., Ph.D., Associate Professor of Aerospace Engineering
David N. Seidman, B.S., M.S., Ph.D., Associate Professor of Materials Science and Engineering
Robert G. Sexsmith, B.A.Sc., M.S.Eng., Ph.D., Assistant Professor of Structural Engineering
Shan-Fu Shen, B.Sc., Sc.D., Professor of Aerospace Engineering
Edwin S. Shepardson, B.S., M.S., Professor of Agricultural Engineering
Dennis G. Shepherd, B.S.Eng., Professor of Mechanical Engineering; Director of the Sibley School of Mechanical Engineering
Benjamin M. Siegel, B.S., Ph.D., Professor of Applied Physics
John Silcox, B.Sc., Ph.D., Professor of Applied Physics; Director of the School of Applied and Engineering Physics
Floyd O. Slate, B.S., M.S., Ph.D., Associate Professor of Structural Engineering
Howard G. Smith, E.E., B.E.E., Ph.D., Professor of Electrical Engineering (on leave, academic year 1971–72)
Julian C. Smith, B.Chem., Chem.E., P.E., Professor of Chemical Engineering (on leave, academic year 1971–72)
James W. Spencer, B.C.E., M.C.E., Ph.D., P.E., Professor of Agricultural Engineering; Vice Director of Cooperative Extension

James F. Stevenson, B.S., M.S., Ph.D., Assistant Professor of Chemical Engineering
Shaler Stidham, Jr., B.A., M.S., Ph.D., Assistant Professor of Operations Research and of Environmental Engineering (on leave, academic year 1971–72)
Peter R. Stopher, B.Sc., Ph.D., Associate Professor of Environmental Engineering
Ravindra N. Sudan, B.A., D.I.I.Sc., D.I.C., Ph.D., Professor of Electrical Engineering and of Applied Physics
Roland A. Sweet, A.A., B.S., M.S., Ph.D., Assistant Professor of Computer Science
George Szentirmai, Dipl.E.E., Cand. of the Technical Sciences, Ph.D., Associate Professor of Electrical Engineering
Chung L. Tang, B.S., M.S., Ph.D., Professor of Electrical Engineering
Robert E. Tarjan, B.S., M.S., Ph.D., Assistant Professor of Computer Science
Howard M. Taylor 3d, B.M.E., M.I.E., Ph.D., Associate Professor of Operations Research and of Environmental Engineering
James S. Thorp, B.E.E., M.S., Ph.D., Associate Professor of Electrical Engineering
Raymond G. Thorpe, B.Chem.E., M.Chem.E., Associate Professor of Chemical Engineering
Hwa-Chung Torng, B.S., M.S., Ph.D., Associate Professor of Electrical Engineering
Kenneth E. Torrance, B.S., M.S.M.E., Ph.D., Assistant Professor of Thermal Engineering
Donald L. Turcotte, B.S., M.Aero.E., Ph.D., Professor of Aerospace Engineering; Representative of the Graduate Field
Robert L. Von Berg, B.S.Ch.E., M.S.Ch.E., Sc.D., P.E., Professor of Chemical Engineering
Norman M. Vrana, B.E.E., M.E.E., Associate Professor of Electrical Engineering (on leave, academic year 1971–72)
Robert J. Walker, B.A., Ph.D., Professor of Computer Science and of Mathematics
Kuo-King Wang, B.S., M.S., Ph.D., Associate Professor of Mechanical Systems and Design
Watt W. Webb, B.S., Sc.D., Professor of Applied Physics
Robert L. Wehe, B.S., M.S., Associate Professor of Mechanical Engineering
Lionel I. Weiss, B.A., M.A., Ph.D., Professor of Operations Research
Charles B. Wharton, B.S., M.S., Professor of Electrical Engineering
Richard N. White, B.S., M.S., Ph.D., P.E., Associate Professor of Structural Engineering
Herbert F. Wiegandt, B.S.Ch.E., M.S.E., Ph.D., Professor of Chemical Engineering
John H. Williams, B.S., M.S., Ph.D., Assistant Professor of Computer Science
Charles C. Winding, B.Ch.E., Ph.D., P.E., Herbert Fisk Johnson Professor of Industrial Chemistry; Professor of Chemical Engineering
George Winter, Dipl.Ing., Ph.D., Class of 1912 Professor of Engineering; Professor of Structural Engineering
George J. Wolga, B.E.P., Ph.D., Professor of Electrical Engineering and of Applied Physics
Robert York, B.S., M.S., Sc.D., P.E., Socony Mobil Professor of Chemical Engineering
Stanley W. Zimmerman, B.S., M.S., P.E., Professor of Electrical Engineering

Engineering College Council

Charles W. Lake, Jr., President, R. R. Donnelley and Sons Company, Chairman of the Council
Alexander M. Beebee, Chairman, Executive and Finance Committee, Rochester Gas and Electric Corporation
Arthur M. Bueche, Vice President and Director, Research and Development Center, General Electric Company
George F. Carrier, Gordon MacKay Professor of Mechanical Engineering, Harvard University
John M. Clark (retired), General Manager, Electro-Chemicals Department, E. I. du Pont de Nemours and Company, Inc.
Robert A. Cowie, President, C & M Auto Spring Company, Inc.
Herbert Dow Doan, former President and Chief Executive Officer, Dow Chemical Company
Walter A. Fallon, Vice President and General Manager, United States and Canadian Photographic Manufacturing, Eastman Kodak Company
Robert F. Gilkeson, President, Philadelphia Electric Company
Meredith C. Gourdine, President, Gourdine Coating Systems Inc.
Jerrier A. Haddad, Vice President of Engineering, Programming, and Technology, and Director of the Laboratory, International Business Machines Corporation
James Hillier, Executive Vice President of Research and Engineering, Radio Corporation of America
Philip E. Hogin, Executive Vice President, Western Electric Company, Inc.
S. C. Hollister (retired), Dean of Engineering, Cornell University
D. Brainerd Holmes, Executive Vice President, Raytheon Company
Frederick G. Jaicks, Chairman and Chief Executive, Inland Steel Company
Dudley N. Schoales, Partner, Morgan, Stanley and Company
Philip Sporn, Consulting Engineer, former Chairman of the Board, American Electric Power Company, Inc.
Winfield W. Tyler, Vice President and Manager, Research Laboratories, Xerox Corporation
J. Carlton Ward, Jr. (retired), Chairman of the Board, Vitro Corporation of America
Wallace E. Wilson, Group Vice President, General Motors Corporation
Frank W. Zurn, President, Zurn Industries, Inc.

Index

Cornell University Announcements

The Cornell *Announcements* are designed to give prospective students and others information about the University. The prospective student should have a copy of the *Announcement of General Information;* after consulting that, he may wish to write for one or more of the following *Announcements:*

New York State College of Agriculture
College of Architecture, Art, and Planning
College of Arts and Sciences
Department of Asian Studies
Education
College of Engineering
School of Hotel Administration
New York State College of Human Ecology
New York State School of Industrial and Labor Relations
Officer Education (ROTC)
Summer Session

Undergraduate preparation in a recognized college or university is required for admission to certain Cornell divisions, for which the following *Announcements* are available:

Graduate School
Graduate School: Course Descriptions
Law School
Veterinary College
Graduate School of Business and Public Administration
Graduate School of Nutrition
Medical College (New York City)
Cornell University—New York Hospital School of Nursing (New York City)
Graduate School of Medical Sciences (New York City)

Requests for the publications listed above may be addressed to

CORNELL UNIVERSITY ANNOUNCEMENTS
Edmund Ezra Day Hall
Ithaca, New York 14850

(The writer should include his zip code.)