Cornell University

Announcements

College of Engineering

1970-71

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: Physical Sciences* 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.

CORNELL UNIVERSITY ANNOUNCEMENTS
Volume 62 of the Cornell University Announcements consists of twenty-three catalogs, of which this is number 13, dated August 26, 1970. Publication dates: twenty-three times a year (four times in August and October; three times in March; twice in June, July, September, and November; once in January, April, May, and December). Publisher: Cornell University, Sheldon Court, 420 College Avenue, Ithaca, New York 14850. Second-class postage paid at Ithaca, New York.

Cornell University

College of Engineering

1970-71

Cornell Academic Calendar

	1970–71*
Registration, new students	Th, Sept. 10
Registration, continuing and rejoining students	F, Sept. 11
Fall term instruction begins, 7:30 a.m.	M, Sept. 14
Citizenship recess:	
Instruction suspended, 1:10 p.m.	S, Oct. 24
Instruction resumed, 7:30 a.m.	Th, Nov. 5
Thanksgiving Day, a holiday	Th, Nov. 26
Christmas recess:	
Instruction suspended, 4:30 p.m.	T, Dec. 22
Instruction resumed, 7:30 a.m.	M, Jan. 4
Fall term instruction ends, 1:10 p.m.	S, Jan. 9
Independent study period begins, 2:00 p.m.	S, Jan. 9
Final examinations begin	W, Jan. 13
Final examinations end	W, Jan. 20
Intersession begins	Th, Jan. 21
Registration, new and rejoining students	Th, Jan. 28
Registration, continuing students	F, Jan. 29
Spring term instruction begins, 7:30 a.m.	M, Feb. 1
Spring recess:	
Instruction suspended, 1:10 p.m.	S, Mar. 27
Instruction resumed, 7:30 a.m.	M, Apr. 5
Spring term instruction ends, 1:10 p.m.	S, May 15
Independent study period begins	M, May 17
Final examinations begin	M, May 24
Final examinations end	T, June 1
Commencement Day	M, June 7

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

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

Contents

Cornell University

Engineering at Cornell

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 know 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; Human Ecology; Hotel Administration; and Industrial and Labor Relations. Also, the University has 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 broad curricula 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 individual 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 650 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 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 of instruction.

Generally, a school has the responsibility 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 "Fields of Instruction." (See p. 8 for those Fields associated with the faculty of the College of Engineering.)

The departments within the College are responsible for advancing both instructional and research activities in their subject matter. For example, much of the mechanical engineering undergraduate program consists of courses offered by the Department of Mechanical Systems and Design and the Department of Thermal Engineering.

Undergraduate Curricula

An undergraduate student may develop a program of studies in any of the areas or fields listed below. With the exception of agricultural engineering, all freshmen and sophomore engineering students are enrolled in the Division of Basic Studies (see p. 25) and must complete the requirements of that division before gaining formal admission to any other school or department in the College.

Bachelor of Science Degree[1]

Agricultural Engineering: a program administered jointly by the Colleges of Engineering and Agriculture. Students are enrolled in the College of Agriculture for the first three years, and during the fourth year in the College of Engineering (see p. 31).

Chemical Engineering (see p. 35).

Civil Engineering (see p. 38).

Electrical Engineering (see p. 48).

Engineering Physics (see p. 53).

Industrial Engineering and Operations Research (see p. 58).

Materials Science and Engineering (see p. 62).

Mechanical Engineering (see p. 66).

College Program: administered by the College Program Committee of the College of Engineering. A flexible curriculum developed to encourage unique and well-defined objectives in engineering not served by one of the aforementioned areas (see p. 44).

Graduate Curricula

The College of Engineering offers two distinct Master's degree programs. One leads to a professional Master's degree—for example, Master of Engineering, and the other to a general degree (Master of Science).

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 degree, offer an integrated curriculum of three years, following completion of the two-year Basic Studies program, to those who seek professional competence.

The Master of Science programs are oriented to students seeking academic or research careers. Both the Master of Science and the Doctor of Philosophy degrees are under the jurisdiction of the University's Graduate School. The professional Master's degrees are administered by the Engineering Division of the Graduate School unless noted otherwise.

1. All Bachelor of Science degrees described are granted by the College of Engineering.

Master of Engineering Degree

Aerospace Engineering: administered by the Graduate School of Aerospace Engineering (see p. 29).

Agricultural Engineering (see p. 33).

Chemical Engineering (see p. 38).

Civil Engineering (see p. 40).

Electrical Engineering (see p. 52).

Engineering Physics (see p. 57).

Industrial Engineering (see p. 62).

Materials Engineering (see p. 65).

Mechanical Engineering (see p. 70).

Nuclear Engineering (see p. 73).

Master of Science and Doctor of Philosophy Degrees

For the general degrees of Master of Science and Doctor of Philosophy, administered by the Graduate School of the University, the University faculty is organized into "Fields of Instruction." Most of these Fields coincide with the respective engineering schools or departments. However, in several instances, the faculty is drawn from many departments within the University.

For each Field there is given below an approved list of titles from which candidates for advanced general degrees choose major and minor subjects. Details of course offerings, financial aid, and residence requirements are described in the *Announcement of the Graduate School: Physical Sciences* (see inside front cover for address). A prospective candidate is invited to write the Graduate Field Representative of the Field in question for detailed information on major and minor area offerings.

AEROSPACE ENGINEERING
Aerospace Engineering, Aerodynamics

AGRICULTURAL ENGINEERING
Agricultural Engineering, Agricultural Structures, Electric Power and Processing, Power and Machinery, Soil and Water Engineering

APPLIED MATHEMATICS
Applied Mathematics

APPLIED PHYSICS
Applied Physics

CHEMICAL ENGINEERING
Biochemical Engineering, Chemical Engineering (General), Chemical Processes and Process Control, Materials Engineering, Nuclear Process Engineering

CIVIL ENGINEERING
Aerial Photographic Studies, Construction Management, Environmental Systems Engineering, Geodetic and Photogrammetric Engineering, Geotechnical Engineering, Hydraulics and Hydrology, Sanitary Engineering, Structural Engineering, Transportation Engineering, Water Resource Systems

COMPUTER SCIENCE
Computer Science, Information Processing, Numerical Analysis, Theory of Computation

ELECTRICAL ENGINEERING
Electrical Engineering, Electrical Systems, Electrophysics

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
Water Resources

The Engineering Campus

Buildings and Laboratories

Ten modern buildings bring engineering teaching and research together in fourteen acres of floor space. Several of these buildings have been gifts from distinguished Cornell alumni. All facilities used by units of the College of Engineering have been built within the past twenty-five years, most within the last decade.

The Graduate School of Aerospace Engineering is in *Grumman Hall,* connected to the southeast wing of Upson Hall. Many of the research laboratories for plasma studies are found in Grumman and Upson Halls, and in *Phillips Hall,* the principal facility of the School of Electrical Engineering.

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 also on the Engineering Quadrangle.

Olin Hall houses the School of Chemical Engineering, and recently constructed *Clark Hall,* the School of Engineering Physics, as well as many research laboratories of the Department of Applied Physics. The Offices of the Basic Studies Division (the freshman and sophomore curricula in engineering) are located in *Hollister Hall,* the facility of the School of Civil Engineering.

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. There is a large structural test bay in Thurston Hall, whose facilities are used by the Department of Theoretical and Applied Mechanics and the Structural Engineering Department of the School of Civil Engineering.

Upson Hall is the home of the Sibley School of Mechanical Engineering and the Department of Mechanical Systems and Design and the Department of Thermal Engineering. Also housed in Upson Hall are 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.

More detailed descriptions of facilities for each of the instructional areas in the College may be found within the section Areas of Instruction. (See pp. 25-80.)

Library Resources

The engineering library, in Carpenter Hall, houses a collection of some 116,000 books and periodicals. Among the specialized holdings of the Engineering Library are a full depository collection of the United States Atomic Energy Commission and similar reports from about twenty foreign countries. The Kuichling Library of Sanitary Engineering includes reports of federal, state, and city health agencies and collected papers on water supply works in various cities. For patent research, the library maintains a file of the British patents and a set of the Official Patent Gazette of the United States Patent Office (patent abstracts). The library resources of the University total more than 3,000,000 volumes.

A special feature of the library in Carpenter Hall is the Browsing Room. Furnished as a club, this paneled room houses about 1,500 selected books in the fields of the humanities and the social studies. It is designed to provide for students and faculty an inviting collection of cultural reading.

Allied and supporting literature in the basic sciences is to be found in the physical sciences library in Clark Hall and in the mathematics library in White Hall.

Undergraduate Degree Program

The undergraduate degree of the College of Engineering is the Bachelor of Science, awarded 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,* where he will spend two additional years completing the requirements for his undergraduate degree.

Students intending to engage in the practice of professional engineering will be encouraged to apply for admission to the Master of Engineering degree program, which requires one extra year of study and is integrated with the junior and senior years.

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.

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* or the *College Program.* (The *Field Programs* are described on pp. 25–80, and the *College Program* is described on p. 44.)

In the new 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.

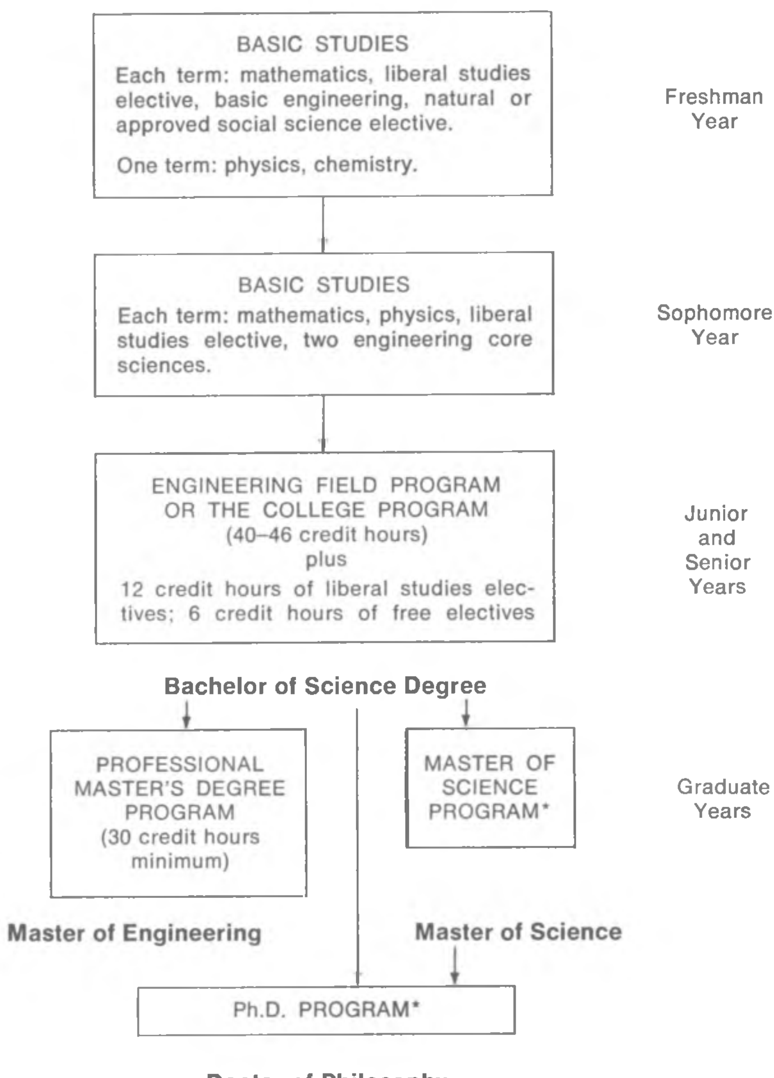
After completing the sophomore year, a Cornell engineering student may enroll in one of the several *Field Programs* or the *College Program.* In either option, he continues work in the core by including twelve credit hours of liberal studies electives and six credit hours of unspecified electives during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

At present, *Field Programs* are offered in chemical, civil, electrical, and mechanical engineering, industrial engineering and operations research, engineering physics, and materials science and engineering. To prepare for entry to one of these Fields, the student should select the appropriate one-term engineering science course during his sophomore year (see the Basic Studies curriculum, p. 27). Approximately 30 percent of the four-year program is devoted to professional studies in a chosen field.

At the completion of the undergraduate *Field Program,* a student may apply for admission to the College's professional Master's degree program, earning that degree in one additional year. The professional Master's degree program represents the level at which graduates will be prepared to seek *professional* engineering employment. The degree includes advanced work in a field begun formally during the junior year and represents a three-year program of integrated studies particularly suited to the requirements of modern engineering practice.

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 law, business, public administration, city and regional planning, or medicine. It will be their decision as to which level of preparation they seek in engineering—the Bachelor of Science or professional Master's—before embarking on other studies. 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.

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



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

The Engineering Cooperative Program

The basic premise of most cooperative education plans is that learning cannot take place on the campus alone. Cornell University has such a plan in which many engineering students spend alternating periods in college and industry after their sophomore year. Unlike most cooperative education programs, however, there is no delay in a participant's graduation date in the Cornell program. Over 600 Cornell engineers have participated in this program since its inception in 1947.

Companies participating in the Engineering Cooperative Program include the following: American Electric Power Service Corporation; AVCO Everett Research Laboratory; Clairol; Cornell Aeronautical Laboratory; Eastman Kodak Company; Emerson Electric Company; Farrel Company; General Electric Company (Binghamton, Schenectady, and Syracuse); General Radio Company; 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.; Texaco Research Center; United Air Lines; Xerox Corporation.

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 (Fall, Summer, Summer), respectively.

	Summer	Fifth Term Courses
JUNIOR YEAR	Fall	Industry I
	Spring	Sixth Term Courses
	Summer	Industry II
SENIOR YEAR	Fall	Seventh Term Courses
	Spring	Eighth Term Courses
	(Bachelor of Science Degree)	
	Summer	Industry III

Graduate study leading to the Master of Engineering degree, can, for example, begin in the fall term following a student participant's third industry period.

Work assignments are chosen for their appropriateness to the student's interests and training. He earns a substantial salary while on assignment 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.

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 including a rank in the upper half of the class 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.

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 obsolete.

Cornell programs to combat technological obsolescence include in-plant courses for firms in the Ithaca area; short courses in various technical subjects; long-term programs for specific industries; and a program of technical service to industry in the Southern Tier of New York State. No academic credit is given for most of the programs.

Courses entitled "Modern Engineering Concepts for Technical Managers" are offered annually. They consist of forty to sixty lecture-seminars which involve topics in materials science, mathematics, operations research, electronics and solid state devices, communication theory, bioengineering, nuclear science, and other areas. The courses emphasize breadth, not depth, and provide a structure for technological achievement and a resource from which to draw ideas and direction for effective technical management.

Intensive short courses, one to two weeks long, are offered in various technical subjects each summer. Twenty courses were offered in 1970; the subjects included topics in computer science, structural design, queuing theory, microscopy, control of water-borne wastes, thermal pollution, natural resource inventories, bioengineering separations, and interpersonal relations for managers. Participants in these courses are drawn from many different states and foreign countries.

A long-term program in construction engineering and administration provides annual two-week sessions held on the Cornell campus during successive Januarys. Lectures on statistics, applications of operations research, and technical developments are coupled with sessions on corporate finance, contract law, labor relations, and other topics of concern to construction engineers. Between campus sessions, participants are encouraged to study, with faculty assistance, relevant technical material. A new group of engineers enters this program each January.

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

Admission to the Degree Programs

Essential dates for freshmen include:

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

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

Financial aid application due: Regular—January 15; decisions announced mid-April; Early Decision Plan—same as admission applications.

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.

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).

Freshman Admission

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, to be taken *not later than January* of their 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 any 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 of students in these circumstances are compared with those of a similar group and are not expected to be as high as the test results 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 Selection Committee.

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 may include leadership capabilities, intellectual creativity, extracurricular activities, counselor recommendations, and other items. The student's commitment to engineering is shown by his investigation of the field and his understanding of the implications of an undergraduate professional education. Does he have the maturity and study and work habits necessary for an engineering curriculum? Superior grades or high College Entrance Examination Board scores are in themselves no guarantee of success in an engineering curriculum, nor are they alone a guarantee of admission.

Advanced Placement

Through cooperation with the advanced placement program of the College Entrance Examination Board and departmental tests given during the fall orientation period, normally one-fifth of the class is given advanced placement or actual college credit for one or more courses of the freshman year. This makes possible more individual development toward a broader liberal program or advanced technical study in line with the student's own inclination.

Superior students, who have achieved advanced placement in mathematics and either chemistry or physics upon graduation from high school, may find it possible to enroll at the sophomore level if they attend the University summer session preceding September matriculation and take the other science. Students with superior performance in the freshman year are encouraged to enroll in honors sections 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 desiring to transfer to the College of Engineering from another Cornell division or from another university or college and who have the equivalent of two or fewer years of applicable college credit, are invited to communicate with the Director of Engineering Admissions, Carpenter Hall.

A special scholarship program has been developed for community or junior college students seeking transfer to the undergraduate degree program in engineering at Cornell. While the procedures for transfer have been rather fully defined for those applying from New York State two-year colleges, students enrolled in two-year programs in other states are encouraged to write for information on this special transfer scholarship program. Inquiries should be directed to the Office of Engineering Admissions, Carpenter Hall, Cornell University, Ithaca, New York 14850.

In exceptional cases, individuals who do not wish to become candidates for any of the undergraduate degrees may be admitted to the College of Engineering as special students. Prospective students who cannot meet the entrance requirements or who do not wish to spend the time required to complete the degree must have had some engineering training and must satisfy the prerequisites for the courses they wish to take. Others with baccalaureate degrees wishing to pursue further work at the undergraduate level may also be admitted as special students. In either instance, individuals should write to the director of the professional school to which they want to be admitted as special students.

Applications for admission and general University information may be obtained by writing the Office of Admissions, Day Hall.

Graduate Admission

A graduate student holding a baccalaureate or equivalent degree from a college or university of recognized standing may pursue advanced work leading to a graduate degree in engineering. Such a student may enter as a candidate either for 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 Physics, Industrial, Mechanical, Materials, 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. 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: Physical Sciences* 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 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 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 based upon research studies; however, they require from three to twelve credit hours of individual work in some aspect of engineering design, including submission of a formal report. Each program also requires completion of a curriculum of related technical courses, differing in content among the several professional degrees. Each curriculum includes some prescribed and some elective courses, with considerable flexibility to permit adaptation to the special needs of the individual student.

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

Expenses and Financial Aid

Expenses

For information on tuition, fees and what they cover, method of payment, refunds, estimates of total expenses, and other matters of general interest, consult the *Announcement of General Information.*

Undergraduate Financial Aid

Scholarships, loans, and employment are available in substantial amounts to aid students in meeting the cost of their education. Over one quarter of a million dollars will be awarded to incoming freshmen in scholarship grants. Loans and jobs will increase this total to about $450,000 in financial aid for the freshman class in the College of Engineering. Over two-thirds of all undergraduate engineering students receive financial aid, and the total resources available for these students equal about one and one-half million dollars per year. Freshmen seeking financial aid should complete the financial aid application 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.

For upperclassmen *who did not* receive aid as incoming freshmen, there are extremely limited sources of financial aid available. Applications for these funds are obtained from the University Office of Scholarships and Financial Aid.

No student should refrain from applying for *admission* because of financial circumstances. Admissions decisions are rendered without regard to financial aid circumstances. After admission has been granted, applicants for financial aid are considered for available financial aid resources. 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 range as high as $4,000 per year.

The following list represents the major scholarship resources specifically awarded to engineering students. Additionally, accepted engineering candidates are considered for University-wide scholarship funds, including the Cornell National Scholarship and the General Motors Scholarship.

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.

Donor	Designated Engineering Field	Total Number of Awards	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	Up to 2,000
John Henry Barr Scholarship	Any	1	Up to 2,000
Seymour L. Baum Memorial Fund	Electrical Engineering	1	200
Robert H. Blackall Scholarship	Any	3	1,250*
Edward P. Burrell Scholarship Endowment	Any	10	1,300*
Carrier Memorial Scholarship	Any	3	1,200
Chrysler Corporation Scholarship	Any	5	500
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
Foundry Educational Foundation Scholarship	Materials Science and Engineering	1 or more	Up to 500
Carl R. Gilbert Memorial Endowment	Any	1	350
Emmet Blakeney Gleason Scholarship Fund	Various Specified Fields	1 or more	Up to 2,200
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
Lockheed National Scholarship	Any	4	3,150
Chester H. Loveland Engineering Scholarship Fund	Civil Engineering	1	Up to 1,550

* Range variable. Figure given is the mean.

Donor	Designated Engineering Field	Total Number of Awards	Amount per Award
The Charles McAllister '87 Endowment	Any	1	350
Harrison D. McFaddin Scholarship Endowment	Any	4	1,000*
John McMullen Scholarship Fund	Any	300*	$1,700*
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
Owens-Illinois Scholarship	Any	4	2,350
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	Tuition or 1,850
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	Up to 1,000
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.

THE JOHN McMULLEN SCHOLARSHIP FUND provides the largest single source of engineering students' assistance. In any given year over 300 undergraduates will have support from this fund, with expenditures from the fund in their behalf exceeding $600,000.

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: Physical Sciences* 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: Physical Sciences.*

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, Cornell United Religious Work, the Career, Summer Plans, and Placement Center, and the Office of Scholarships and Financial Aid.

Beginning in the fall 1970 the College of Engineering will have an *Engineering Counseling Center.* It will be responsible for the development and administration of the freshman and sophomore advising program and will serve as an educational information resource center for all students in the College. Each engineering student has a faculty adviser who can assist in personal counseling and on questions pertaining to his educational program 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 Student Personnel, 221 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 Career, Summer Plans, and Placement Center are available to all engineering students for summer and permanent employment. The Office of Student Personnel, in cooperation with the placement service, annually arranges interviews between students and prospective employers. Selected engineering faculty serve as placement advisers with whom students may discuss their career objectives, whether for employment or graduate study. Information about companies is available in both the Placement Center and the Office of Student Personnel in Carpenter Hall, and students may discuss specific employment opportunities and the procedures of job placement with the staff of either office.

Areas of Instruction

Basic Studies

Degrees Offered: The Division of Basic Studies is responsible for the administration of the freshman and sophomore curricula in the College.
Courses of instruction are listed on pp. 81–86.

HOLLISTER HALL
Mr. H. G. Smith, director; Messrs. W. H. Bray, C. K. Paul. Freshman Engineering Courses Committee: Mr. J. P. Leinroth, chairman; Mr. R. G. Sexsmith, assistant chairman; Messrs. D. L. Bartel, W. H. Bray, M. S. Burton, J. R. Cooke, A. H. Nilson, R. E. Osborn, C. K. Paul, C. Pottle, E. N. Scala. College Advising and Counseling Committee: Mr. D. F. Berth, director; Messrs. N. M. Brice, M. S. Burton, T. R. Cuykendall, D. C. Johnson, N. M. Vrana, R. N. White.

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.

A sequence of four courses in mathematics is required of all underclassmen. Because of advanced placement and credit received upon matriculation, however, 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, the sequence begins in term 2; however, freshmen with superior mathematics preparation may begin this sequence in term 1. This will enable them to take a fourth course in physics during term 4 if they wish.

For students not taking a second course in chemistry and/or a fourth course in physics, any natural or contextually relevant social science course may be elected instead. This elective is in addition to the four liberal studies electives that are offered in the freshman and sophomore years. The liberal studies electives may include courses in humanities, social sciences, modern foreign languages, history, and expressive arts.

New Core Curriculum

Beginning in the fall 1970, a new sequence of freshman engineering courses will be offered. Included will be instruction in FORTRAN; an introduction to engineering design and graphics; and a series of "mini-courses" that will focus on engineering activity ranging from projects, field trips, and discussion groups to case studies of engineering-related problems and issues.

During the sophomore year students whose career goals require them to do so may substitute introductory courses in the natural sciences (e.g., biology, organic chemistry) for their liberal studies electives by delaying the taking of these electives until their junior and senior years. Besides continuing their studies in mathematics and physics, all students except those who are planning to major in chemical engineering take four courses in engineering science during the sophomore year. These must be chosen from the areas outlined on p. 27. Only one of these four courses may be specified as a prerequisite for entrance to a particular upperclass program (the Field Programs). The wise selection of these courses is of considerable importance to the student's subsequent program of studies and should be made in close consultation with a faculty adviser. (Students who are planning to major in chemical engineering as upperclassmen see footnote, p. 27.)

Honors Sections and Advanced Placement

Through cooperation with the advanced placement program of the College Entrance Examination Board and departmental tests given during the fall orientation period, students are enrolled in course sections consistent with their individual level of preparation. Approximately one-fifth of the entering class is given advanced placement and actual college credit for one or more courses of the freshman year.

Superior students who have achieved two terms of advanced placement in mathematics and either chemistry or physics upon graduation from high school may find it possible to enroll as a sophomore by completing the other science course required of freshmen prior to their enrollment at the University in September. Students with superior performance in the freshman year may enroll in sophomore honors sections.

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 C minus or better, 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 (approximately a B+ average). All engineering students are required to complete twenty-four hours of liberal studies courses before graduation; twelve hours of liberal studies electives must be completed by students in this Division as part of the College requirement. The University requires that students satisfactorily complete one course in physical education during each of the underclass terms.

Freshman students entering the College of Engineering in the fall of 1970 will take the following program of courses:

Freshman Year

TERM 1	Credit 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	Credit Hours
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	Credit 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

TERM 4	Credit 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 students can enroll in the Field Program at the beginning of their junior year. The following courses will be offered during the academic year 1970–71. Students must complete four of them, choosing a minimum of one course from three of the four groups.

Engineering Core Sciences

GROUP I CHEMISTRY AREA	Credit Hours
Organic Chemistry*	
Physical Chemistry*	
Introduction to Thermodynamics 3631	3

GROUP II MATHEMATICS AREA	Credit Hours
Introductory Engineering Probability 9160†	3
Basic Engineering Statistics 9170	4
Computers and Programming 202	3

GROUP III MECHANICS and MATERIALS AREA	Credit Hours
Mechanics of Solids 1021‡	3
Introduction to Applied Mechanics 1001	3
Mechanical Properties of Materials 6261	3
Dynamics 1031	3
Electrical Properties of Materials 6262	3

GROUP IV PHYSICS and ELECTRICITY AREA	Credit Hours
Introduction to Electrical Systems 4210 ‖	3
Contemporary Topics in Applied Physics 8117	3

* 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. However, freshmen matriculating at Cornell in 1970 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. (They will take these courses in lieu of two of their sophomore year engineering core sciences.)

† Required for Industrial Engineering.

‡ Required for Mechanical Engineering or Civil Engineering.

‖ Required for Electrical Engineering or Engineering Physics.

Aerospace Engineering

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

Courses of instruction are listed on pp. 86–87.

GRUMMAN HALL
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.

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 equivalent) in any branch of engineering, mathematics, or the physical sciences from qualified institutions, provided that their undegraduate 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.

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 the Office of the Director. 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 Master of Engineering (Aerospace) degree. It is not recommended that candidates apply for admission at midyear, except in very unusual circumstances.

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. The subjects listed represent typical course sequences acceptable for the requirements for the Master of Engineering (Aerospace) degree. The faculty may modify this basic list to suit the needs, interests, and background of individual candidates. Courses are currently available to 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. Other course sequences leading to specialization in allied fields can also be arranged; for example, space power, aerophysics, chemical kinetics, etc. Faculty members and visiting staff frequently offer additional courses (besides those listed on pp. 86–87) in their specialties.

The M.Eng. (Aerospace) is awarded for course work only and requires successful completion of two six-hour sequences from those listed below, six hours of mathematics (1180–81 or 415–416 or equivalent), six hours of electives, attendance at the weekly colloquium, and one advanced seminar (two hours) each term. This is 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.

COURSE SEQUENCES AVAILABLE FOR MASTER OF ENGINEERING (AEROSPACE)

	Credit Hours
7101–02, Advanced Kinetic Theory, 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), Aerospace 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

ELECTIVES: LIST B

	Credit Hours
7001, Introduction to Aeronautics	3
7002, Introduction to Aerospace Systems	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

ELECTIVES: LIST B (cont.)

	Credit Hours
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 Degrees

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 the following areas. 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 forms an essential 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 bring the School into close contact with several other divisions of the University (including the Center for Applied Mathematics, the Laboratory for Plasma Studies, and the Center for Radiophysics and Space Research).

Others are pursuing investigations in the area 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, Cornell University, Ithaca, New York 14850.

Agricultural Engineering

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

Courses of instruction are listed on pp. 88–89.

RILEY-ROBB HALL
Mr. O. C. French, director; Messrs. R. D. Black, J. R. Cooke, R. B. Furry, W. W. Gunkel, 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.

[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. Registration for the fourth and final year is 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 from farms.

Riley-Robb Hall, with over 100,000 square feet of floor area, 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, containing 78,000 feet of floor area, is used for waste management pilot plant studies.

The Department has an extensive research program supported through the Cornell Agricultural Experiment Station, which provides many students with opportunities for part-time work during the academic year and summer periods.

Agricultural engineering specialization does not require a period of practice before graduation. However, faculty advisers will encourage and assist advisees in obtaining summer work experience which will be appropriate for their career objectives.

Scholastic Requirements

To remain in good standing, a student must have a weighted average for the term of C minus (1.7 quality points) or above.

The Degree Programs

Bachelor of Science

For a complete description of the courses in agriculture, consult the *Announcement of the College of Agriculture.*

TERM 1	*Credit 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	3
or	
Biological Science 103	3
Liberal Studies Elective	3

TERM 2	*Credit Hours*
Mathematics 192, Calculus for Engineers	4
Physics 112	4
Agricultural Engineering 152, Introduction to Agricultural Engineering Measurements	3
Biological Science 103 or 101	3
Liberal Studies Elective	3

TERM 3	*Credit Hours*
Mathematics 293, Engineering Mathematics	4
Physics 233	4
Engineering 1001, Introduction to Applied Mechanics	3
Engineering Science	3
Liberal Studies Elective	3

TERM 4	*Credit Hours*
Mathematics 294, Engineering Mathematics	3
Physics 235	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.

TERMS 5 to 8 to include:

(a) A structured program of forty to forty-six hours, with a minimum of twelve hours of engineering science courses and a minimum of eleven hours of 400-level agricultural engineering courses. The remainder of the program will be designed to provide depth in the student's major areas of interest.

(b) A minimum of twelve hours of biological sciences and agricultural electives.

(c) A minimum of twelve hours of liberal studies electives. The minimum number of credit hours for the program is 133 and the maximum that can be required is 142.

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. and *(d)* electric power and processing.

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 Degrees

Flexible programs leading to the M.S. and Ph.D. are offered in the following areas of specialization for either a major or a minor: agricultural structures, power and machinery, soil and water engineering, and electric power and processing. Minors for those majoring in agricultural engineering may be selected from the engineering, agricultural, or basic sciences. A broad and active research program, supported by the Cornell Agricultural Experiment Station, gives the student an opportunity to select a challenging research project for his thesis. Assistantships and traineeships are available with annual stipends that are comparable to those offered at other Land Grant institutions. For more detailed information write the Office of the Graduate Field Representative, Riley-Robb Hall. A brochure entitled *Agricultural Engineering at Cornell* may be obtained from this Office.

Applied Physics

Degrees Offered: Master of Science, Doctor of Philosophy.

Courses of instruction are listed on pp. 89-93.

CLARK HALL
Mr. J. Silcox, acting chairman; Messrs. B. W. Batterman, K. B. Cady, D. D. Clark, R. K. Clayton, D. R. Corson, T. R. Cuykendall, C. T. Dum, H. H. Fleischmann, P. L. Hartman, 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, Visiting staff: Messrs. A. J. Bennett and W. I. Goldburg.

Members of the University's *Graduate Field of Applied Physics* include, in addition to those of the Department of Applied Physics, the following: Messrs. N. W. Ashcroft, P. L. Auer, J. M. Ballantyne, R. W. Balluffi, S. H. Bauer, J. M. Blakely, T. A. Cool, E. T. Cranch, P. C. T. de Boer, L. F. Eastman, M. E. Fisher, T. Gold, M. O. Harwit, H. H. Johnson, E. J. Kramer, C. Lee, C. Y. Li, R. McFarlane, P. R. McIsaac, A. L. Ruoff, D. N. Seidman, C. L. Tang, D. L. Turcotte, C. B. Wharton.

Graduate study in the Field of Applied Physics offers the opportunity to achieve proficiency in physics, mathematics, and applied science. The course program, which resembles a major in physics, is particularly suitable for students preparing for a scientific career in areas of applied science based on principles and techniques of physics and in associated areas of physics. It 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 is compatible with an approach based on the application of principles of physics and mathematics. Individual programs of study are planned to meet the needs and interests of each student, and programs involving several academic disciplines and topics that are undergoing transition from fundamental physics to applied science 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.

The faculty of the Graduate Field of Applied Physics consists of the faculty of the Department of Applied Physics and additional members from other departments in the Colleges of Engineering and Arts and Sciences. This representation makes possible programs in a broad range of areas of applied and engineering physics.

The graduate program in applied physics is an extension to the graduate level of the same philosophy on which the undergraduate curriculum in engineering physics is based. The formal course program at the graduate level contains a core of physics and mathematics courses and provides for advanced study and research in a variety of areas of physics and applied science. Details of the program, requirements for admission, and areas of advanced study are given in the *Announcement of the Graduate School: Physical Sciences* and in a brochure available from the Office of the Field Representative, Applied Physics, Clark Hall, Cornell University, Ithaca, New York 14850.

Research in which graduate students in applied physics currently participate includes 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 infrared 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. These topics represent just a few of the interesting variety of timely areas available for study and research in applied physics.

Chemical Engineering

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

Courses of instruction are listed on pp. 93–96.

OLIN HALL
Mr. K. B. Bischoff, director; Messrs. G. G. Cocks, V. H. Edwards, R. K. Finn, P. Harriott, J. E. Hedrick, J. P. Leinroth, F. Rodriguez, G. F. Scheele, J. C. Smith, R. G. Thorpe, R. L. Von Berg, D. M. Watt, Jr., H. F. Wiegandt, C. C. Winding, R. York.

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.

The chemical engineering program at Cornell 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 specialities in more depth. The School of Chemical Engineering offers special programs in biochemical 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 setting up 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

The Field Program in Chemical Engineering offers a coordinated sequence of chemical engineering courses starting 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. 25–27. Although the student planning to enroll in the professional chemical engineering program remains in the Division of Basic Studies for the first two years and can transfer to other programs during that time, he selects chemical engineering at the end of the freshman year and registers for Chemistry 287–288, 289–290, and Engineering 5101 during the sophomore year. (Students who are sophomores in 1970–71 also take Engineering 5102.)

Bachelor of Science

TERM 5	Credit Hours
Chemistry 357, Organic Chemistry	3
Engineering 5304, Introduction to Rate Processes	3
Engineering 5102, Equilibria and Staged Operations	3
Engineering 5257, Materials	5
Liberal Studies Elective	3

TERM 6	Credit Hours
Engineering 5303, Analysis of Stage Processes	3
Chemistry 358, Organic Chemistry	3
Chemistry 355, Organic Chemistry Laboratory	2
Engineering 5203,* Chemical Processes	4 or 0
Free Elective(s)†	3 or 6
Liberal Studies Elective	3

TERM 7	Credit Hours
Engineering 5106, Reaction Kinetics and Reactor Design	3
Engineering 5353, Unit Operations Laboratory	3
Engineering 5742,* Polymeric Materials	3 or 0
Free Elective(s)†	3 or 6
Liberal Studies Elective	3

TERM 8	Credit Hours
Engineering 5103, Chemical Engineering Thermodynamics	3
Engineering 5624, Process Evaluation	3
Free Elective(s)†	6
Liberal Studies Elective	3

* Engineering 5203 *or* 5742 is required. (If both are taken, one may count as an elective.)

† Electives must include two engineering core sciences.

The College Program: Majors and Minors

Students pursuing the four-year *College Program,* described on p. 44, 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 undergraduate students who intend to seek a doctorate. One of the prime objectives of this program is to minimize the time required to obtain this degree, thus increasing the number of Ph.D.s available for teaching, research, and highly technical positions in industry.

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.

Students in this program can complete a Master of Science degree by the end of their fifth year. During the fourth year, a research project is begun in place of the project-laboratory course which is required otherwise. This research may continue through the fifth year to meet the thesis requirement for the M.S. degree. At the end of the sixth year, these students will have completed all the course work required for the Ph.D., and should have enough research experience to select and complete a Ph.D. thesis during the following fifteen months. If this program is followed successfully, the doctorate is achieved in three years and one summer beyond the Bachelor's degree.

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

A student holding a baccalaureate or equivalent degree in chemical engineering from a college of recognized standing may 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, and physics. 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: Physical Sciences.* 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, Cornell University, Ithaca, New York 14850.

Civil Engineering

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

Courses of instruction are listed on pp. 96–107.

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

Civil 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 engineering activities. The civil engineer is a major contributor 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-trained civil engineers who can meet the basic needs of society with efficiency, economy, and safety.

The wide range of subjects which are the concerns of the civil engineer are generally grouped into a number of sub-fields and specializations. At Cornell, there are four subject departments in Civil Engineering:

Environmental Systems Engineering (see p. 41)

Geotechnical Engineering (see p. 42)

Structural Engineering (see p. 43)

Water Resources Engineering (see p. 43)

These departments provide courses for graduate study leading to advanced degrees and also those courses necessary to support the undergraduate curriculum in civil 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 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 engineering technology and substantial opportunity for liberal study.

Most students go on to graduate study in the fifth year following completion of the baccalaureate. Three main paths of advanced work at Cornell are:

1. Graduate study in the Field of Civil 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 civil 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 engineering.

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

Bachelor of Science (Field Program)

The first four terms are described on p. 27 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 Engineering Field Program. It is recommended, but not required, that students planning to enter civil engineering take Dynamics 1031 and 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 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	*Credit Hours*
Engineering 1031, Dynamics*	3
Engineering 2301, Fluid Mechanics	3
Engineering 2701, Structural Engineering I	3
Engineering 9170, Probability and Statistics*	3
Liberal Studies Elective	3

TERM 6	*Credit Hours*
Engineering 6261, Mechanical Properties of Materials*	3
Engineering 2501, Environmental Quality Engineering	3
Engineering 2401, Soil Mechanics	3
Engineering 2603, Engineering Economics and Systems Analysis	3
Liberal Studies Elective	3

TERM 7	*Credit Hours*
Civil Engineering Electives (2)†	6
Technical Elective	3
Free Elective	3
Liberal Studies Elective	3

TERM 8	*Credit Hours*
Civil 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.

† The four civil engineering electives shall be chosen so that at least one course shall be from three of the four subject areas for which the four departments have responsibility; namely, Environmental Systems Engineering, Geotechnical Engineering, Structural Engineering, and Water Resources Engineering.

Bachelor of Science (College Program)

As an alternative to the Field Program, a student with a strong interest in an interdisciplinary and/or specialized program may wish to consider the *College Program* (see p. 44). Where this involves one of the areas of civil engineering, either as a major or minor subject, the various department chairmen 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, and sanitary engineering and oceanography.

Master of Engineering (Civil)

This degree is available as a curricular type of professional degree, the general requirements for which are stated on p. 19. 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 Engineering. A substantial portion of the work may be in one of the areas of concentration within civil 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. They require submission of a thesis.

In the Field of Civil Engineering a number of special areas of concentration are available either as major or minor subjects. For clarity, these concentrations are identified as follows with the departments which provide the related graduate instruction. *Environmental Systems Engineering:* construction management, transportation engineering, environmental systems engineering. *Geotechnical Engineering:* geodetic and photogrammetric engineering, geotechnical engineering, aerial photographic studies. *Structural Engineering:* structural engineering, structural mechanics. *Water Resources Engineering:* hydraulics and hydrology, water resource systems, sanitary engineering. A brief description of the activities of each of these four departments follows.

Environmental Systems Engineering

Mr. G. P. Fisher, chairman; Messrs. P. L. Bereano, L. M. Falkson, A. H. Meyburg, W. R. Lynn, C. S. ReVelle, S. Stidham, Jr., H. M. Taylor, 3d.

Environmental systems engineering is a unique area of activity, the main thrust of which is the application of systems analysis, operations research, and economics to the complex technological problems of modern society which fall predominantly in the public sector. It is concerned with methods of allocation of resources and with enhancement of the quality of information upon which to base rational decision making and public investment. Particular emphasis is placed on transportation systems; air, water, and other natural resource systems; project management; solid waste disposal; and public health, medical, and public services systems. There is special interest in the problems of urbanization, including an integrated approach to the many technological and planning aspects of modern urban areas and to associated social and political factors.

Substantial effort is directed to the treatment of large-scale problems such as interurban and urban transportation networks, transport terminal facilities and intermodal transfer efficiency, river basin studies, disease management, optimal location of transportation links and public facilities and associated land use patterns and land values. The economics, planning, and management of all forms of man-made and natural environment, and the associated decision-making process, are stressed. Much use is made of mathematical modeling and computers.

Through established relationships with the Departments of City and Regional Planning, Operations Research, and Water Resources Engineering, the Cornell Medical College, and many other divisions of the University, students are encouraged to take advantage of a large variety of ancillary course offerings that support the general program of study.

Master of Science and Doctor of Philosophy candidates majoring in environmental systems engineering follow graduate programs comprising systems analysis, economic analysis, and a specific application area. Candidates are considered for advanced degrees who have undergraduate or graduate work in any area of civil engineering, in industrial engineering and operations research, and in economics. Students with other backgrounds and well-developed career objectives will also be considered for graduate study.

Undergraduates may concentrate on environmental systems engineering by proper choice of electives in the Civil Engineering *Field Program* or through a *College Program.* A College Program in Environmental Systems Engineering usually comprises basic courses in operations research, economic analysis, and an introduction to one or more of the application areas described above. Underclassmen in the Division of Basic Studies who contemplate a College Program in Environmental Systems Engineering will find it advantageous to take Introductory Engineering Probability (IE 9160) as an engineering science course and Economic Analysis (CE 201–202) as a liberal studies elective.

Geotechnical Engineering

Messrs. D. J. Belcher, W. L. Hewitt, T. Liang, G. B. Lyon, A. J. McNair, D. A. Sangrey.

Geotechnical engineering is concerned with those aspects of civil 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 environment and to define the nature of the problems. Soil mechanics and foundation engineering provide the quantitative link with the measurement of soil and rock properties and their use in the design process. Subgrade and pavement design are also covered.

The laboratories, used for both instruction and research, are well equipped. 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 held in the libraries, and these are used in both photogrammetric and aerial photographic studies. A broad range of geodetic instruments is also 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.

Structural Engineering

Mr. R. H. Gallagher, acting chairman; Messrs. P. Gergely, W. McGuire, A. H. Nilson, 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 a diversity of government agencies and by 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.

Water Resources Engineering

Mr. C. D. Gates, chairman; Messrs. V. C. Behn, W. H. Brutsaert, L. B. Dworsky, A. W. Lawrence, J. A. Liggett, D. P. Loucks, R. C. Loehr.

Faculty in this Department are concerned with undergraduate instruction, advanced study, and research in environmental quality control, fluid mechanics, hydraulics, hydrology, sanitary engineering, and water resource systems engineering. Departmental objectives fall into three general categories: (1) the development of fundamental knowledge of phenomena and principles pertinent to the above areas through theoretical analysis and experimentation; (2) the application of this knowledge, along with analytical, computational, and laboratory skills, to the analysis and design of processes, facilities, and systems for environmental quality control, water quantity control, and waste management; (3) the application of mathematical modeling, economic theory, and systems analysis to problems in environmental resource planning and management and in environmental quality control.

Undergraduates may concentrate in these subject areas either by choosing the Civil Engineering Field Program or by electing the College Program. Individuals considering graduate study in this area should have a baccalaureate degree in engineering science, a branch of engineering, or a physical science.

Additional Information

A number of fellowships and assistantships are available to graduate students in civil engineering. Prospective graduate students should consult the *An-*

nouncement of the Graduate School: Physical Sciences. A brochure entitled *Civil Engineering at Cornell,* may be obtained by writing to the Office of the Graduate Field Representative, Civil Engineering, Hollister Hall, Cornell University, Ithaca, New York 14850.

The College Program

Degree Offered: Bachelor of Science

CARPENTER HALL
College Program Committee: Mr. W. H. Erickson, chairman; Messrs. V. C. Behn, B. Boley, R. K. Finn, F. K. Moore, 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, a department in the School of Civil Engineering). In planning a College Program, a student should thoughtfully and carefully consider his future educational and professional objectives (especially the prerequisites for any formal graduate study he may be interested in).

The Program is a highly individualized one, worked out between the student and his advisers. All College Programs, however, consist of an engineering major and a minor. The minor may be chosen from the College of Engineering or from some other division 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 Graduate School of Business and Public Administration, the School of Industrial and Labor Relations, and the College of Human Ecology. Graduates of the College Program have continued their educations 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, materials science, or social psychology; 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; structural engineering and architecture; transportation and regional planning.

Admission

Students may apply to enter the College Program at the beginning of the second term of the sophomore year. They will become College Program majors in the junior year, when 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 not expected that the student will compile such a listing on his own, but that he will develop his 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. The application will be endorsed by the professors representing the proposed major and minor areas and then submitted to the College Program Office in 221 Carpenter Hall. (Applications may be obtained from this Office.)

The application is then either approved or disapproved by the College Program Committee. No minimum grade point average is necessary for admission, but grade point averages will be considered with regard to the type of program students wish to undertake.

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 a minor, the minor area being educationally related to the major in meeting the student's objective); (2) a minimum of twelve credit hours of liberal studies electives; (3) a minimum of six credit hours of free electives (which may be added to either the major or the minor portion of the approved program to strengthen the student's background in this area).

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.

College Program in Engineering Science

The faculty 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.

College Program in Computer Science

Students interested in concentrating in the area of computer science during their 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:

CS 202, Computers and Programming (engineering core science)
CS 203, Discrete Structures
CS 222, Introduction to Numerical Analysis
CS 385, Introduction to Automata Theory
CS 409, Data Structures
CS 411, Programming Languages
CS 412, Translator Writing
CS 413, Systems Programming and Operating Systems

(Descriptions of these courses may be found on pp. 107–111.)

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.

Computer Science

(Colleges of Engineering and of Arts and Sciences)

Degrees Offered: Master of Science, Doctor of Philosophy.

Courses of instruction are listed on pp. 107–111.

UPSON HALL

Mr. J. Hartmanis, chairman; Messrs. K. M. Brown, R. L. Constable, R. W. Conway, J. E. Dennis, Jr., D. Gries, J. E. Hopcroft, E. Horowitz, D. J. Jackson, W. L. Maxwell, J. Moré, H. L. Morgan, C. Pottle, G. Salton, A. C. Shaw, R. A. Wagner, R. J. Walker, T. Wilcox, J. H. Williams.

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 linked to the central computer to provide an analog-digital interface and graphical display equipment.

The Degree Programs

Undergraduate

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* (described on p. 44) leading to the degree of Bachelor of 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.*

A typical computer science major in the *College Program* would consist of the following sequence of computer science courses:

Term 3: CS 202, Computers and Programming (3 hrs.)
Term 4: CS 222, Introduction to Numerical Analysis (3 hrs.)
Term 5: CS 203, Discrete Structures (3 hrs.)
CS 409, Data Structures (4 hrs.)
Term 6: CS 385, Introduction to Automata Theory (3 hrs.)
Term 7: CS 411, Programming Languages (4 hrs.)
CS 413, Systems Programming and Operating Systems (4 hrs.)
Term 8: CS 412, Translator Writing (4 hrs.)

There is considerable flexibility in the program and other courses may be substituted, depending on the student's interests.

Graduate

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, and information organization and retrieval.

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, Cornell University, Ithaca, New York 14850.

Electrical Engineering

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

Courses of instruction are listed on pp. 111–121.

PHILLIPS HALL

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, S. K. Chang, G. C. Dalman, L. F. Eastman, W. H. Erickson, D. T. Farley, T. L. Fine, J. Frey, T. Gold, C. E. Ingalls, F. Jelinek, M. Kim, W. H. Ku, C. A. Lee, R. L. Liboff, S. Linke, R. A. McFarlane, H. S. McGaughan, P. R. McIsaac, C. W. Merriam III, R. A. Moog, 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. Visiting staff: Mr. I. Cederbaum.

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. 19 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: Physical Sciences.*

3. Advanced studies in fields other than engineering 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 three main themes are necessary to prepare its students adequately. These themes are called *Electrophysics, Systems,* and *Laboratory.* They are interrelated, and the curriculum contains an integrated series of required courses in each.

Electrophysics is chiefly concerned with our 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, 4411, and 4412 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 the general methods of analysis required for such systems, the physical significance of the solutions, and some aspects of the design of systems applicable to such ends as 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, 4401, and 4402 as a sequence of courses in the systems area of study.

The *Laboratory* sequence emphasizes 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 systems and network research, 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 Arecibo Observatory in Puerto Rico his internationally recognized facilities which include two radar transmitters each having a peak-power output of 2,500,000 watts and operating in conjunction with a 1000-foot-diameter antenna. These facilities are used for research studies of the upper atmosphere and for radio-astronomy and radar-astronomy research.

The Degree Programs

Bachelor of Science (Field Program)

TERM 5	Credit Hours
Engineering 4301, Analysis of Electrical Systems I	4
Engineering 4311, Electromagnetic Fields and Waves	4
Engineering 4321, Electrical Laboratory I	4
Liberal Studies Elective	3
See footnote below*	3

TERM 6	
Engineering 4302, Analysis of Electrical Systems II	4
Engineering 4312, Electromagnetic Fields and Waves	4
Engineering 4322, Electrical Laboratory II	4
Liberal Studies Elective	3
See footnote below*	3

TERM 7	Credit Hours
Engineering 4401, Deterministic Signals in Linear Systems	4
Engineering 4411, Quantum Theory and Applications	4
E. E. Elective with laboratory	3 or 4
Liberal Studies Elective	3
See footnote below*	3

TERM 8	
Engineering 4402, Random Signals in Linear Systems	4
Engineering 4412, Solid State Physics and Applications	4
E. E. Elective with laboratory	3 or 4
Liberal Studies Elective	3
See footnote below.*	

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

SCHOLASTIC REQUIREMENTS

A student failing to make satisfactory progress toward his degree, evidenced by a low average, by course failures, or by low grades in major courses, may be given a trial term or suspended from the School. In order to qualify for graduation, an electrical engineering student must have a minimum grade-point average of 1.8 in third- and fourth-year courses.

FIELD ELECTIVE COURSES

The curriculum of the School of Electrical Engineering provides for a wide selection of elective technical courses which may be incorporated into the Field Programs of the students. The selection of these courses can begin with Term 7 and will hopefully permit students to pursue their individual interests in further depth.

THEORY OF SYSTEMS AND NETWORKS
- 4450 Bioelectric Systems
- 4503 Theory of Linear Systems
- 4504 Theory of Nonlinear Systems
- 4507–08 Random Processes in Electrical Systems
- 4571 Network Analysis
- 4572 Network Synthesis

ELECTROMAGNETIC THEORY
- 4511 Electrodynamics
- 4514 Microwave Theory
- 4567 Antennas and Radiation

LABORATORY
- 4421–22 Advanced Electrical Laboratory

ELECTRONICS
- 4431–32 Electronic Circuit Design
- 4433–34 Semiconductor Electronics I and II
- 4436 Electronic Processing of Audio Signals
- 4531–32 Quantum Electronics I and II
- 4534 Nonlinear and Quantum Optics
- 4535–36 Solid State Devices I and II
- 4537 Integrated Circuit Techniques
- 4538 Electromagnetic Properties of Solids
- 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

RADIO AND PLASMA PHYSICS
- 4461 Wave Phenomena in the Atmosphere

4462 Radio Engineering
4464 Elementary Plasma Physics and Gas Discharges
4551–52 Upper Atmosphere Physics I and II
4561 Introduction to Plasma Physics
4564 Advanced Plasma Physics
4565–66 Radiowave Propagation I and II
4661 Kinetic Equations

COMMUNICATIONS, INFORMATION, AND DECISION THEORY
4472 Introduction to Algebraic Coding
4501 Systems with Random Signals and Noise
4502 Statistical Aspects of Communication
4672 Foundations of Inference and Decision Making
4673 Principles of Analog and Digital Communication
4674 Transmission of Information
4676 Decision and Estimation Theory for Signal Processing

COMPUTING SYSTEMS AND CONTROL
4481–82 Feedback Control Systems
4483 Analog Computation
4484 Analog-Hybrid Computation
4487–88 Switching Theory and Systems
4505 Approximation Techniques
4506 Optimization Techniques
4588 Bionics and Robots
4681 Random Processes in Control Systems

COURSES OF INTEREST TO OTHER CURRICULA
4110 Computer Appreciation
4210 Introduction to Electrical Systems
4921–22 Electrical Engineering Laboratory
4435 Electronics and Music
4940 Introductory Electrical Engineering

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 such that they can profitably study 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 extending the abilities of the electrical engineer to other fields.

The requirements for the M.Eng. (Electrical) degree follow.

1. A minimum total of thirty credit hours of advanced technical course work in the Field of Electrical Engineering or in related subjects.
2. A minimum of two sequences of two courses in advanced electrical engineering (chosen from a designated list).
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 government and have involved 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 and a minimum final grade of C for any courses counting toward this degree.

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 Degrees

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 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., and 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, Cornell University, Ithaca, New York 14850.

Engineering Physics

Degrees Offered: Bachelor of Science, Master of Engineering (Engineering Physics). The Graduate Field of Applied Physics offers the Master of Science and Doctor of Philosophy degrees (see page 34).

Courses of instruction are listed under Applied Physics on pp. 89–93.

CLARK HALL
Mr. T. R. Cuykendall, director; Messrs. B. W. Batterman, K. B. Cady, D. D. Clark, R. K. Clayton, H. H. Fleischmann, P. L. Hartman, J. A. Krumhansl, A. F. Kuckes, 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, J. Silcox, W. W. Webb, G. J. Wolga.

Creativity and innovation in engineering and applied science depend significantly on basic and advanced knowledge in physics and applied mathematics and on the techniques of applying this knowledge to engineering problems. Accordingly, the engineering physics program provides this kind of knowledge and encourages this approach among students with an interest and competence in such areas.

The student pursues thorough and advanced courses in physics and applied mathematics. He is encouraged to develop insight into the application of concepts. Thus, he may proceed from a basic understanding of matter and energy through a knowledge of techniques to a number of applied themes.

Through electives, he may open for himself the way to several modern technological areas such as recent advances in gasdynamics, aerodynamics, plasma, radio astronomy, astrophysics, other space sciences, modern topics in solid state physics, systems development, and nuclear science and engineering.

Study in this field provides a sound foundation for graduate study in physics, applied physics, nuclear science and engineering, aerospace engineering, and other areas of engineering research based on physics and applied mathematics. Also, the curriculum has proved to be an excellent foundation for employment in the newer technological industries that transcend the boundaries of the established engineering professions. Therefore, students in the program have the opportunity to qualify for: (1) the five-year professional Master of Engineering programs in engineering physics, nuclear engineering, and aerospace engineering, each created for those who wish to practice the newer applications of physical science; (2) further education in professional fields enriched by a background in applied science; or (3) positions in industry at the end of four years, usually to continue learning on the job and often to participate in advanced training programs.

Laboratory and Research Facilities

The faculty members of the School of Engineering Physics have a wide variety of research interests and activities in the fields of applied physics and engineering sciences. The prospective student who is interested in learning more details of research activities undertaken should consult the *Announcement of the Graduate School: Physical Sciences.* A bulletin entitled *Graduate Research in Applied Physics* may be obtained from the Graduate Field Representative, Department of Applied Physics, Clark Hall, Cornell University, Ithaca, New York 14850.

Candidates for the Bachelor's degree may in their senior year undertake projects relating to one of the research areas. Equipment is available for projects and research studies in the areas of electron microscopy and diffraction, solid state and surface physics, low-energy nuclear physics, nuclear chemistry, and nuclear reactor physics and technology. Students also may participate actively in the University-wide plasma physics program.

Clark Hall is the center for undergraduate affairs in the School of Engineering Physics such as student records, scheduling, and advising. Graduate activities and projects related to the Master of Engineering (Engineering Physics) degree may be carried out in one of several laboratories of the College of Engineering depending upon the nature of the work and the affiliation of the professor in charge.

The Degree Program

The engineering physics field major requires considerable interest and proficiency in physics and mathematics. While students may enroll in the engineering physics program from the regular sections of physics and mathematics, registration in honors sections is desirable and strongly recommended.

Of the core engineering sciences that may be completed before the end of the fourth semester 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. Familiarity with the fundamentals at this level provides a basis for building deeper and wider conceptual ability and applied skills.

The electives need not all be formal course work; the qualified student may earn credit through informal study under the personal direction of a faculty member.

By suitable selection of electives during his third and fourth years of undergraduate schooling or through studies for the Master of Engineering (Engineering Physics) degree, the qualified student may prepare for a career in one of many specialized fields of engineering. Some of these are listed below.

AEROSPACE ENGINEERING. The undergraduate program in engineering physics is particularly suited for work in aerospace engineering at either the undergraduate or graduate level.

PLASMA PHYSICS. A major in engineering physics provides an excellent background in subjects such as electromagnetic field theory, thermodynamics and statistical mechanics, and fluid mechanics, all of which would be useful for a career in the area of plasma physics.

NUCLEAR ENGINEERING. The student interested in the nuclear energy field or in nuclear reactor power developments should choose his electives from courses in reactor physics, nuclear measurements, advanced heat transfer, and the physics of solids underlying radiation damage problems. His attention is directed to courses 8303, 8309, 8312, 8351, and to 5760, 6873, and 7201. Additionally, closely related courses such as Physics 444 are also available.

MATERIALS SCIENCE. The core program of the engineering physics curriculum combined with electives in applied physics (e.g., 8262, 8211) and materials science and engineering and specialized seminars provide an excellent preparation for research in materials science, a field that often holds the key to further technological progress. Students can find ample possibilities for graduate projects by joining one of the active research groups studying such topics as surface physics, properties of thin films, electron microscopy and diffraction, relaxation phenomena and their relation to dislocations and other defects, critical phenomena, magnetoresistivity, and superconductivity.

SPACE SCIENCE AND TECHNOLOGY. Engineering physics provides an excellent preparation for undergraduate or graduate specialization in this challenging field. Qualified students may elect courses in gasdynamics, radio wave propagation, optics, astronomy, relativity, and other related courses. Several faculty members have strong research interests in this field and are available to supervise senior research projects related to their areas of specialization. Students may undertake projects as a part of the work of the Center for Radiophysics and Space Research.

Bachelor of Science

This degree may be obtained by satisfactorily completing the following curriculum or its equivalent. (Terms 1 through 4 are described on p. 27.)

TERM 5	*Credit Hours*
Math 421, Applicable Mathematics	4
Engineering 8155, Intermediate Electromagnetism	3
Engineering 8133, Mechanics of Particles and Solid Bodies	3
Technical Elective	3 or 4
Engineering 4921, Electrical Engineering Laboratory	1
Liberal Studies Elective	3 or 4
TERM 6	
Math 422, Applicable Mathematics	4
Engineering 8156, Intermediate Electrodynamics	3
Engineering 8134, Mechanics of Continua	3
Technical Elective	3 or 4
Engineering 4922, Electrical Engineering Laboratory	1
Liberal Studies Elective	3 or 4

TERM 7	*Credit Hours*
Mathematics 423, Applicable Mathematics	4
Physics 443, Atomics and Introductory Quantum Mechanics	4
Engineering 8121, Thermodynamics and Fluid Mechanics	3
Free Elective	3
Liberal Studies Elective	3 or 4
TERM 8	
Physics 444, Nuclear and High-Energy Particle Physics	4
or	
Physics 454, Introductory Solid State Physics	4
or	
Engineering 8309, Low-Energy Nuclear Physics	4
or	
Engineering 8501, Introduction to the Physics of Atoms and Molecules	3
Physics 410, Advanced Experimental Physics	4
Engineering 8122, Statistical Mechanics and Kinetic Theory	3
Free Elective	3
Liberal Studies Elective	3 or 4

The College Program

The *College Program* (see p. 44), leading to the degree of Bachelor of Science, may be pursued through a suitable selection of courses and themes in physics and applied physics. Such a program might be a combination of physics, applied physics, and biological sciences as the beginning of a career in biophysics. Each program must be approved after formulation by the student and cannot be specified in approved form in advance. Some partial course combinations from which a student might formulate a program follow.

MAJOR IN NUCLEAR ENGINEERING
Physics 436, Modern Physics
Engineering 8303, Introduction to Nuclear Science and Engineering
Engineering 8351, Nuclear Measurements Laboratory
Engineering 5760, Nuclear and Reactor Engineering

MINOR IN NUCLEAR ENGINEERING
Physics 436, Modern Physics
Engineering 8303, Introduction to Nuclear Science and Engineering
Engineering 8351, Nuclear Measurements Laboratory

MAJOR IN ENGINEERING PHYSICS
Engineering 8155, Intermediate Electrodynamics
Engineering 8156, Intermediate Electrodynamics
Physics 443, Atomics and Introductory Quantum Mechanics
Physics 410, Advanced Experimental Physics

SCHOLASTIC REQUIREMENTS

A student is expected to pass every course for which he is registered, to maintain each term a grade point average of about 2.3 or higher, and to demonstrate aptitude and competence in the basic subject matter of the curriculum.

A student whose performance falls below these requirements will be academically deficient, and may be refused permission to continue his studies in the School.

Master of Engineering (Engineering Physics)

The objectives of the four-year engineering physics program are well served by an additional year of advanced study and by the initiation of individual and independent work. The student has the opportunity to master advanced topics in physics and can extend his skill in his chosen engineering specialties. He must carry out an independent project that provides experience in defining objectives, making plans, pursuing a program, and reporting conclusions. Thus, he is expected to develop and display the skills and the responsibility needed for working independently or cooperatively toward engineering goals without firmly prescribed guidelines other than his own knowledge and judgment.

From the Master's program the student may move into development work, for example in industry, or he may go on to more advanced graduate study in the Field of Applied Physics or in some other related field.

Most of the laboratory facilities for research in the areas described above are made available for the student projects required for the M.Eng. (Engineering Physics) degree. Each project is supervised by a member of the faculty active in this area.

FINANCIAL ASSISTANCE

Financial assistance in amounts up to full tuition and fees is available (based on academic merit and on financial need) to all those admitted to the program. Application forms for admission and scholarship are available in the Office of the School of Engineering Physics. The deadline for their submittal is March 1; all applicants are notified by April 1.

ADMISSION REQUIREMENTS

1. For Cornell students: A grade point average of 2.5 or higher in the four-year Field Program in engineering physics will allow admission without petition.

2. For transfer students: Evidence is required that the candidate has the ability and preparation to complete successfully the program of study.

REQUIREMENTS FOR THE DEGREE

1. An informal study or project of at least six credit hours value which requires individual effort and a formal report and which may be either experimental or analytical.

2. (a) If the project is experimental, one course in mathematics or applied mathematics; or (b) if it is analytical, one term of advanced laboratory,

Physics 510, or an equivalent laboratory course to be taken upon approval of the chairman of the program.

3. A graduate-level course in quantum mechanics, such as Physics 572 or its equivalent.
4. A minimum of six hours in a graduate-level course sequence.
5. A senior or graduate-level course in statistical mechanics such as Chemistry 596, EP 8122, or their equivalent.
6. Attendance at a sequence of scheduled University seminars and colloquia chosen in consultation with the chairman of the program.
7. Electives in the area of technology and applied science.
8. Completion of thirty semester hours credit beyond the Bachelor's degree.

Master of Science and Doctor of Philosophy Degrees in Applied Physics

Graduate study in the Field of Applied Physics offers the opportunity to achieve proficiency in physics, mathematics, and applied science. The course program resembles a major in physics, and applied physics is particularly suitable for students preparing for a scientific career in areas of applied science based on principles and techniques of physics and in associated areas of physics. It 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 principles and techniques.

Master of Engineering (Nuclear)

This program is described elsewhere in the *Announcement;* see p. 73.

Environmental Systems Engineering

See page 41.

Geotechnical Engineering

See page 42.

Industrial Engineering and Operations Research

Degrees Offered: Bachelor of Science, Master of Engineering (Industrial). The Graduate Field of Operations Research offers the Master of Science and Doctor of Philosophy degrees; see p. 75.

Courses of instruction are listed on pp. 121–127.

UPSON HALL
Mr. B. W. Saunders, director: Messrs. R. N. Allen, R. E. Bechhofer, L. J. Billera, M. Brown, R. W. Conway; Mrs. S. C. Dafermos; Messrs. M. J. Eisner, H. Emmons, H. P. Goode, W. F. Lucas, W. L. Maxwell, H. Morgan, G. L. Nem-

hauser, N. U. Prabhu, S. Saltzman, M. W. Sampson, A. Schultz, Jr., S. Stidham, Jr., H. M. Taylor 3d, L. I. Weiss.

Industrial Engineering is concerned with the analysis, design, and operation of integrated systems of men, materials, and equipment to perform a useful function. Operating systems which appear to be very different from each other physically may have a number of common characteristics which allow their analysis and synthesis to be performed by modern industrial engineering (systems engineering) methodology and techniques. *Operations research,* on the other hand, is concerned with research into the underlying phenomena and interactions that are present in operating systems for the purpose of better understanding the behavior of individual elements within and the total system performance in loosely coupled man-machine systems. Such systems are found typically in production, distribution, transportation, merchandising, planning, and research and development activities, to name a few representative functional areas of interest. Organizationally they are found in industrial, commercial, and governmental groups; hence the field of application is exceedingly broad and the relevance of the work extremely important for the needs of modern society with its ever increasing complexity and costs. The modern industrial engineer has, therefore, a tremendous range of opportunities to apply the "science of operations" in the analysis, synthesis, and design of many types of loosely coupled man-machine systems and their associated information and control systems.

The Cornell concept of education for a career in modern industrial engineering (operations research or management science as well) stresses analytical methodology; hence, the course work emphasizes the relevant mathematics, computer science, costs, and economic analysis. These topics are the result of continuing research for many years by the staff in applied probability topics such as queuing and inventory theories; in statistical topics such as decision theory, ranking procedures, and sequential decision problems; in several topics of mathematical programming; in computer science with emphasis on information and data processing and experimentation with digital simulation; in production planning through scheduling studies; and in capital budgeting and investment planning. New staff members are expanding this research to include such topics as game theory, combinatorial analysis, and network theory with special emphasis on transportation networks.

By entering the Field of Industrial Engineering, the student will be introduced to many of these topics during the first two years of the three-year program leading to the Master of Engineering (Industrial) degree. For those terminating their study after two years (a total of four, including those in the Division of Basic Studies) the Bachelor of Science degree is awarded. The student may then choose to transfer to another professional field, e.g., law, city and regional planning, or business and public administration, to enroll at another university, or to seek employment. Inasmuch as the four-year degree represents only the first phase of the education required for the engineering degree, students are strongly urged first to complete their full engineering education by qualifying for the M.Eng. (Industrial) degree (awarded after one more year of study).

Students who desire to apply the analytical methodology learned in industrial engineering to another professional field can do this by their choice of employment. If additional formal education seems desirable, either the Master of City and Regional Planning or the Master of Business Administration can be earned in one additional year. Any student contemplating such a combined program is urged to consult the director of the School to work out the best sequence of electives to achieve his special goals. The student who has identified an interest and ability in teaching or research and desires to embark on a program of study leading to a M.S. or Ph.D. degree (at Cornell or elsewhere) should consult with either the director of the School or the chairman of the Department of Operations Research as early as possible.

Laboratories and Research Facilities

The program in industrial engineering is under the direction of the faculty of the School of Industrial Engineering and Operations Research. The principal instruction is given in the Department of Operations Research, with other departments (e.g., Computer Science) providing instruction in certain methodological specialties of interest to industrial engineers. Facilities include some conference-type class and seminar rooms, a methods laboratory, and computing rooms containing adding machines and desk calculators. Many of the activities required in the operation of the University, certain community activities, and operations in industrial plants located in the area supply real-life research problems and projects in engineering design. Also, a basic laboratory for the Department is the Cornell Computing Center (see p. 47). While every engineering student at Cornell learns how to program problems for the computer in his freshman year, industrial engineering upperclassmen are required to learn considerably more about computer science, with problems requiring use of a high-speed digital computer assigned in many of the courses. In recent years the Department has consistently been one of the largest users of the computer on the campus.

The Degree Programs

Bachelor of Science

The first four terms are described on p. 27 of this *Announcement*. During the second year (terms 3 and 4) of the curriculum in the Division of Basic Studies, four engineering core sciences must be elected, with two normally being taken each term. Beginning in the fall 1970 freshmen who intend to major in industrial engineering and operations research must elect the engineering science course Introductory Engineering Probability (9160) during their sophomore year as a prerequisite for entering the Field of Industrial Engineering and Operations Research. Computers and Programming (202) may also be elected as one of the four engineering sciences since it is required in term 5. However, it probably would be more desirable for students to choose other engineering sciences to establish a broader base on which to build. Other engineering science courses considered to be of special relevance for the industrial engineer/operations researcher are Introduction to Electrical Systems (4210); Introduction to Applied Mechanics (1001) or The Mechanics of Solids (1021); and Introduction to Thermodynamics (3631).

TERM 5	*Credit Hours*
Engineering 9301, Man-Machine Systems and the Industrial Engineer	3
Engineering 9360, Introduction to Probability Theory with Engineering Applications	4
Computer Science 202, Computers and Programming*	3
Behavioral Science Elective	3
Liberal Studies Elective	3
TERM 6	
Engineering 9350, Cost Accounting, Analysis and Control	4
Engineering 9370, Introduction to Statistical Theory with Engineering Applications	4
Engineering 9383, Applications of Computer Science in IE/OR	4
Behavioral Science Elective	3
Liberal Studies Elective	3

TERM 7	*Credit Hours*
Engineering 9310, Industrial Engineering Analysis	4
Engineering 9320, Deterministic Models in IE/OR	4
Technical Elective	3
Free Elective	3
Liberal Studies Elective	3
TERM 8	
Engineering 9311, Industrial Engineering Design	4
Engineering 9321, Probabilistic Models in IE/OR	4
Technical Elective	3
Free Elective	3
Liberal Studies Elective	3

* Computer Science 301/401 is the required fifth term course for students who are sophomores in 1970–71.

SCHOLASTIC REQUIREMENTS

A student in the School of Industrial Engineering and Operations Research who does not receive a passing grade in every course for which he is registered, who fails in any term or summer session to maintain an average grade of at least a C, or who is not otherwise making substantial and steady progress toward the completion of his degree may be suspended.

ELECTIVE COURSES

The student can develop an extremely valuable and flexible program by using his elective hours wisely and in accordance with some plan. The total elective content in the upperclass years totals thirty-three hours out of the sixty-eight required; nearly 50 percent of the curriculum can be specified, then, by the student within rather broad guidelines. An additional technical elective course can be added if Computer Science 202 is taken as part of the engineering core sciences during the sophomore year.

With this freedom, the student might choose to develop his program in depth in certain areas in anticipation of advanced study leading to a career in research. On the other hand, he might choose to develop his program in breadth by exploring other engineering fields that are increasingly dependent on the systems approach and the analytical methodolgy taught by the School of Industrial Engineering and Operations Research. The advisers and/or director are prepared to assist the student in achieving his objectives in the most effective way, but it is incumbent upon the student to define clearly his objectives. Programs combining "systems" work from electrical and civil engineering are possible. Some students wish to develop their expertise by combining studies in city and regional planning with their studies in industrial engineering and operations research. Others may wish to emphasize transportation problems or environmental and pollution problems, combining these with the systems methodology covered in their required IE/OR courses. The flexibility provided is great and, consequently, many specialties can be developed to accommodate individual interests.

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.

FALL TERM	*Credit Hours*
Engineering 9526, Mathematical Models—Development and Application	4
Engineering 9580, Digital Systems Simulation	4
Engineering 9593, Industrial Engineering Graduate Seminar	1
Engineering 9598, Project	4
Technical Elective	3

SPRING TERM	*Credit Hours*
Engineering 9521, Production Planning and Control	4
Engineering 9551, Advanced Engineering Economic Analysis	4
Engineering 9594, Industrial Engineering Graduate Seminar	1
Engineering 9599, Project	4
Technical Elective	3

Materials Science and Engineering

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

Courses of instruction are listed on pp. 127–130.

BARD HALL

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.

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.

Materials science is the oldest and best established of the interdisciplinary engineering fields, although it has not always had that name. The successful study and solution of materials problems usually requires a thorough understanding of materials properties in terms of basic physical and chemical concepts, as well as a knowledge of the engineering sciences and an interest in frontier problems of technology. Interaction with other engineering disciplines is often required for the solution of practical problems.

Materials science is primarily concerned with a basic understanding of material characteristics and methods of manipulating them. This understanding is sought from the macroscopic to the atomic scale. Materials engineering also deals with applications, particularly with the selection, processing, characterization, and testing of materials for specific engineering tasks.

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. New facilities for studying the structure of solids by physical measurement, microscopy, metallography, and x-ray diffraction are available. Equipment for processing materials by casting, welding, heat treatment, compacting and sintering, deformation, and many of the newer processing procedures is included. 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, 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

At Cornell 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 presented 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. Through suitable choice of electives there can be considerable program flexibility.

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.

Bachelor of Science

Course programs for terms 1–4, administered by the Division of Basic Studies, are described on p. 27.

MATERIALS SCIENCE AND ENGINEERING PROGRAM

TERM 5	*Credit Hours*
Engineering 6031, Structure of Materials I	3
Engineering 6035, Thermodynamics	3
Technical Elective	3
Technical Elective	3
Liberal Studies Elective	3–4

TERM 6	*Credit Hours*
Engineering 6032, Structure of Materials II	3
Engineering 6034, Mechanical Properties of Materials	3
Engineering 6036, Thermodynamics of Condensed Systems	3
Technical Elective	3
Liberal Studies Elective	3–4

TERM 7	*Credit Hours*
Engineering 6041, Kinetics	3
Engineering 6043, Senior Materials Laboratory I*	3
Technical Elective	3
Free Elective	3
Liberal Studies Elective	3–4

TERM 8	*Credit Hours*
Engineering 6042, Electrical and Magnetic Properties	3
Engineering 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.

ELECTIVE COURSES

The programs in materials science and engineering have a substantial number of elective hours during the last two years. This flexibility allows students who have special interests within the Field or in other divisions of the College or University to plan educational programs that complement their interests. 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. 44–46 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.

ADMISSION REQUIREMENTS

1. For Cornell students: A grade point average of 2.5 or higher in the four-year Field Program in Materials Science and Engineering will allow admission without petition.
2. For transfer students: Evidence is required that the candidate has the ability and preparation to complete successfully the program of study.

REQUIREMENTS FOR THE DEGREE

1. A project of at least twelve credit hours is required. This project, usually experimental although it can be analytical, will be carried out under the supervision of a member of the faculty and will require individual effort and initiative.
2. Six credit hours of courses in mathematics or applied mathematics are required. 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 are required to bring the total credit hours to thirty.

Graduate Study

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.*

A student who enters with an undergraduate degree may register for either the M.S. or Ph.D. degree. Toward the end of his first year, the student's progress is reviewed by his Special Committee. If that group takes favorable action then or at a later date, the student is accepted as a Ph.D. candidate; he may then proceed directly to the Ph.D. without taking the M.S.

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 Hail, Cornell University, Ithaca, New York 14850.

Mechanical Engineering

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

Courses of instruction are listed on pp. 130–136.

UPSON HALL

Mr. D. G. Shepherd, director; Messrs. D. L. Bartel, J. F. Booker, A. H. Burr, B. J. Conta, T. A. Cool, D. Dropkin, G. B. DuBois, H. N. Fairchild, B. Gebhart, R. L. Geer, 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.

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 production 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: *Mechanical Systems and Design* (see p. 68), and *Thermal Engineering* (see p. 68). 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 objective is to give the student an understanding of the design of a mechanical engineering system. For those completing the five years of study culminating in the Master of Engineering (Mechanical) degree, the objective of system design is met by a design project suggested and monitored by an industrial organization. In this way, the student has an opportunity to practice his engineering knowledge in an individual manner on a realistic problem.

The Field Program has been arranged to provide a great deal of flexibility. Supplementary to the upperclass elective courses (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 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 are 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 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 machine 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: Physical Sciences.*

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, G. B. DuBois, R. L. Geer, 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. While the offerings of the Department allow a student to elect courses that will equip him for a wide variety of engineering tasks, the Department also offers areas of concentration in vehicle engineering and in manufacturing and design.

Vehicle engineering is concerned with the transportation needs of modern society. It includes the consideration of wheeled, tracked, 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 the material needs of society. Emphasis is placed on the interrelation of design and manufacture. Attention is paid to the newer production techniques (e.g., electrochemical 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 production, 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, 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. Relevant electives treat pollution problems, refrigeration and air conditioning, combustion engines, and the more fundamental topics already mentioned.

Theoretical and experimental research interests include 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

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. 27). 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 are required, of which twelve must be in the Field. Two of these are Field electives for all students. The remaining eight courses are specified as four liberal studies, two mechanical, and two free electives. The last-named may be any courses in the University to which the student can gain admission (including six hours of advanced ROTC). Three of the Field courses may be satisfied by core sciences taken in the Division of Basic Studies. The Field Program is as follows:

1031, Dynamics* (engineering science course)
3631, Introduction to Thermodynamics* (engineering science course)
3400, Engineering Materials† (Field course)
or
6261, Mechanical Properties of Materials (engineering science course)
4940, Introductory Electrical Engineering† (Field course)
or
4210, Introduction to Electrical Systems (engineering science course)
3623, Fluid Mechanics
3625, Heat Transfer and Transport Processes
3325, Mechanical Design and Analysis
3326, Systems Dynamics
3053, Mechanical Engineering Laboratory
Mathematics or Mathematical Methods course‡
Restricted Field Elective‡
Restricted Field Elective‡

* If taken before entry to the Field Program, other electives may be substituted. (These other electives may be chosen from the natural sciences or mathematics or courses offered by the College of Engineering.)

† If taken before entry to the Field Program, other electives may be substituted. If not taken before entry to the Field Program, the alternative Field course will be taken.

‡ Chosen from a list of approved courses.

For a student who has only the entry requirement of Mechanics of Solids (1021), the following program is recommended. However, 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 engineering core sciences.

Bachelor of Science

TERMS 1–4
See Division of Basic Studies Curriculum (p. 27).

Suggested Course Sequence

TERM 5
Engineering 1031, Dynamics
Engineering 3631, Introduction to Thermodynamics
Engineering 3400, Engineering Materials
Mathematics Elective*
Liberal Studies Elective

TERM 6
Engineering 3325, Mechanical Design and Analysis
Engineering 3623, Fluid Mechanics
Engineering 4210, Introduction to Electrical Systems
Field Elective
Liberal Studies Elective

TERM 7
Engineering 3625, Heat Transfer and Transport Processes
Engineering 3326, Systems Dynamics
Engineering 3053, Mechanical Engineering Laboratory
Technical Elective
Liberal Studies Elective

TERM 8
Field Elective
Technical Elective
Free Elective
Free Elective
Liberal Studies Elective

* Chosen from a list of approved courses.

Master of Engineering (Mechanical)

This degree is available as a curricular type of professional degree, the general requirements for which are stated on p. 19. Of the thirty credit hours required, the mechanical engineering program allows nine elective hours together with considerable latitude in the choice of a laboratory course and the design project. In this way, an option is possible in a particular area, e.g., machine dynamics and control, mechanical analysis and development, vehicles and propulsion, propulsion engines, thermal power, thermal environment, manufacturing engineering, material removal, etc.

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 requirements described below.

FALL TERM	*Credit Hours*
Mathematics	3
Engineering 3361, Advanced Mechanical Analysis	3
Engineering 3090, Mechanical Engineering Design Project	3
Engineering Laboratory* or Mechanical Engineering Elective	3
Technical Elective	3

SPRING TERM	*Credit Hours*
Mathematics	3
Engineering 3651, Advanced Thermal Science	3
Engineering 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, 1151 or, on a more advanced level, by 1180, 1181. 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. All projects are suggested, monitored, and reviewed by industrial 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 is previously satisfied when fulfilling undergraduate elective requirements, twenty-one hours of the thirty-hour requirement are, to a large extent, elective. In this way, the student has wide latitude to obtain a specific educational objective.

Some scholarship aid is available. Admission and scholarship application forms may be obtained by writing to the Office of the Chairman, Graduate Professional Engineering Program, 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, Cornell University, Ithaca, New York 14850.

Master of Science and Doctor of Philosophy Degrees

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: Physical Sciences.*

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 applications and further information may be obtained from the Office of the Field Representative, Sibley School of Mechanical Engineering, Upson Hall, Cornell University, Ithaca, New York 14850.

Mechanical Systems and Design

See p. 68.

Nuclear Science and Engineering

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

Courses of instruction are listed under Applied Physics on pp. 89–93.

WARD LABORATORY OF NUCLEAR ENGINEERING
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.

Nuclear science and nuclear engineering are concerned with the understanding, development, and practical application of the scientific knowledge of nuclear reactions and radiations. In this broad context, nuclear science and engineering treat the production of neutrons, gamma radiation, radioisotopes, and transmutation of elements. The aims of the programs at Cornell are to provide the student with a thorough understanding of the laws and principles upon which nuclear systems are based, to develop research abilities, and to develop the skills of applying basic principles to engineering problems. To implement these aims, Cornell offers three graduate degrees: the research degrees, Master of Science and Doctor of Philosophy, administered by the Graduate Field of Nuclear Science and Engineering; and a professional degree, Master of Engineering (Nuclear), administered by the Engineering Field of Nuclear Engineering.

The faculty at Cornell believes the specialized education of nuclear engineers lies at the graduate level; for this reason no Bachelor of Science program in the nuclear field is offered. Appropriate undergraduate programs which can lead to graduate study in nuclear engineering are civil, chemical, electrical, or mechanical engineering, or engineering physics. In addition, the *College Program* offers a wide range of majors and minors in the above fields as well as a major and minor in nuclear engineering.

Individuals preparing for graduate study in nuclear engineering should select their technical electives carefully to insure that they meet the entrance requirements for the graduate program. Whether or not a student is preparing for graduate study in nuclear engineering, there are a number of courses in the nuclear field available to him as technical electives. These courses are described under the specific engineering field which is in charge of the course content.

Nuclear engineering uses the basic sciences of chemistry, physics, and mathematics and the skills of metallurgical, chemical, civil, electrical, and mechanical engineering. The nuclear engineering faculty is made up of members from each of these engineering fields and from engineering physics.

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

The College Program

Students who wish to begin specialization in nuclear science and engineering at the undergraduate level may consider the following courses subject to the approval of the *College Program Committee.*

MAJOR IN NUCLEAR ENGINEERING
Engineering 8312, Nuclear Reactor Theory I
Physics 436, Modern Physics
Engineering 8351, Nuclear Measurements Laboratory
Engineering 5760, Nuclear and Reactor Engineering
or
Engineering 8303, Introduction to Nuclear Science and Engineering
Engineering 8309, Low Energy Nuclear Physics

MINOR IN NUCLEAR ENGINEERING
Physics 436, Modern Physics
Engineering 8303, Introduction to Nuclear Science and Engineering
or
Engineering 5760, Nuclear and Reactor Engineering
Engineering 8351, Nuclear Measurements Laboratory

Master of Engineering (Nuclear)

This two-term degree program is intended both for students who want a terminal degree and for students who want an interim degree before undertaking doctoral study in nuclear science and engineering. The program develops the basic principles of nuclear reactors and shows a student how his field of undergraduate specialization may be applied to nuclear engineering problems. The recommended entrance requirements include:

1. A baccalaureate degree in engineering, applied science, or the equivalent;

2. Physics, including atomic and nuclear physics;
3. Mathematics, including advanced calculus;
4. Thermodynamics.

Students should make every effort to complete the entrance requirements before beginning the program; this may be done in some cases by informal study during the summer. The thirty credit hours for the degree include the following courses:

FALL TERM
Engineering 8312, Nuclear Reactor Theory I
Engineering 8333, Nuclear Reactor Engineering
Engineering Elective
Mathematics or Physics Elective

SPRING TERM
Engineering 8351, Nuclear Measurements Laboratory
Engineering 8309, Low-Energy Nuclear Physics
Engineering Elective
Engineering Design Project

The engineering electives are to be in a subject area relevant to nuclear engineering (e.g., nuclear materials, nuclear chemical engineering, fluid dynamics, heat transfer, energy conversion, automatic feedback control systems). Typical examples of electives taken by the professional Master's degree students follow.

Engineering 8334, Nuclear Engineering Design Seminar
Physics 443, Atomics and Introductory Quantum Mechanics
Engineering 5505–5506, Advanced Transport Phenomena
Engineering 3672, Energy Conversion
Engineering 3680, Advanced Convection Heat Transfer
Engineering 3651, Advanced Thermal Science
Mathematics 415–416, Mathematical Methods of Physics
Engineering 1180–1183, Methods of Applied Mathematics
Engineering 7201–7202, Introductory Plasma Physics and Introductory Magnetohydrodynamics
Engineering 6873, Materials Science for Engineers

Master of Science and Doctor of Philosophy

A candidate for either the M.S. or the Ph.D. degree may choose as his major subject nuclear science or nuclear engineering. The detailed program of studies is flexible and is not prescribed as a curriculum, but is planned by each individual student and the faculty members of his Special Committee. This system, which is the tradition of graduate work at Cornell, is well suited for interdisciplinary Fields such as Nuclear Science and Engineering. Formal courses do not dominate the pattern of graduate education. Independent research leading to the writing of a thesis and formal and informal discussions with staff members and other students are vital parts of the program.

Typical core courses in the major Field of either Nuclear Science or Nuclear Engineering follow.

Mathematics 415–416, Mathematical Methods in Physics
Physics 561, Theoretical Physics I
Physics 572, Quantum Mechanics
Physics 574, Intermediate Quantum Mechanics
Engineering 8309, Low-Energy Nuclear Physics
Engineering 8310, Nuclear Structure Physics
Engineering 8312–8313, Nuclear Reactor Theory I and II
Engineering 8351, Nuclear Measurements Laboratory

At the heart of the research degree programs is the student's thesis research. Areas of research in nuclear science include nuclear chemistry, low-energy nuclear physics, theory of neutron interactions with matter, radiochemistry, radiation chemistry, activation analysis, and radiation detection. Areas of research in nuclear engineering include neutral particle transport theory, reactor statistics and dynamics, nuclear materials and fuels, basic processes in the production and use of power from nuclear reactions, selected problems in nuclear reactor design and optimization, and relationships between energy sources, energy needs, and a clean environment.

Additional information on the M.S. and Ph.D. programs is available in the *Announcement of the Graduate School: Physical Sciences.* Further information may be obtained from the Office of the Graduate Field Representative, Ward Laboratory, Cornell University, Ithaca, New York 14850.

Operations Research

Degrees Offered: Master of Science, Doctor of Philosophy.

Courses of instruction are listed on pp. 121–127.

UPSON HALL
Mr. R. E. Bechhofer, chairman; Messrs. L. J. Billera, M. Brown, R. W. Conway; Mrs. S. C. Dafermos; Messrs. M. J. Eisner, H. Emmons, 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., S. Stidham, Jr., H. M. Taylor 3d, L. I. Weiss.

Major and Minor Subjects

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 among the major techniques employed. Optimization techniques such as mathematical programming (linear, nonlinear, and probabilistic), 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).

Because a doctoral dissertation must represent a fundamental contribution to theory and application, students who elect work in this area are expected to acquire considerable knowledge of the theory of probability and statistics. In addition, 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 selecting 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 developing 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 represent 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. The application and integration of equipment is emphasized rather than 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 information theory 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.

Appropriate Minor Subjects

The following minor subjects have been chosen most frequently in recent years: computer science (Computer Science), econometrics (Economics), environmental systems engineering (Environmental Systems Engineering), managerial economics (Business and Public Administration), mathematics (Mathematics), regional planning (City and Regional Planning), and water resources (Water Resources Engineering).

Admission Requirements

As a prerequisite for graduate study leading to the degree of Master of Science or Doctor of Philosophy with a major in the Field of Operations Research, the candidate must have graduated from an institution of recognized standing with a Bachelor's degree in engineering, mathematics, economics, or the physical sciences. In addition, he 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 major and minor subjects. It is strongly recommended that all applicants to the Field take the Graduate Record Examination and submit the results along with their application for graduate study. Fellowship and assistantship applicants must submit scores from this examination.

Further information (including a brochure entitled *Operations Research at Cornell*) about any of the graduate programs may be obtained by writing to the Office of the Graduate Field Representative, Department of Operations Research, Upson Hall, Cornell University, Ithaca, New York 14850.

Structural Engineering

See p. 43.

Theoretical and Applied Mechanics

Degrees Offered: Master of Science, Doctor of Philosophy.

Courses of instruction are listed on pp. 136-140.

THURSTON HALL

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

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 on p. 44.

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;

(6) continuum mechanics;

(7) 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, Cornell University, Ithaca, New York 14850.

College Program

A modern engineering curriculum must be flexible and responsive to changes in society's technological needs. On the other hand, there are basic physical principles, the foundations of science, which are unchanging.

The College Program in Engineering Science was devised to reflect this fundamentally constant character of engineering and at the same time to permit specialization. Faculty members of the Department are prepared to sponsor individual undergraduate students desiring a program in engineering science as a College Program. The course details of such a program will depend on the educational goal of the student and will be worked out in consultation with a member of the faculty.

Science as an analytical or experimental discipline is not the only aspect of this program to be emphasized, however. An equally significant feature of this program is its flexibility. The curriculum has been designed to provide maximum freedom of choice in the context outlined, so the student can prepare himself for an educational goal not necessarily met by any of the existing Field Programs. For example, basic study in engineering science may be supplemented by study in astronomy, applied mathematics, physics, chemistry, or biology. All programs will have the general form outlined on p. 45 of this *Announcement.*

It is important to note that the curriculum is a College-approved curriculum equivalent to a Field Program; there are no specific courses in the curriculum beyond those required by College legislation. Instead, only general directions of study are specified.

The College Program in Engineering Science is intended to prepare the graduate engineer to perform such functions as comprehension, modeling, and analysis of important engineering and social problems. Specialists in engineering science will find many opportunities to work in industry and educational institutions and may apply their skills in other fields, such as bioengineering or some nonengineering activity. The demand for these specialists, particularly those with advanced degrees, is increasing, and there is every indication that in the foreseeable future the demand for graduates in this field will exceed the supply.

Individuals interested in playing a major role in the development of a specialized, analytical-experimental College Program, should discuss their aims with Professor B. A. Boley, chairman of the Department of Theoretical and Applied Mechanics, or Professor R. H. Lance.

Thermal Engineering

See p. 68.

Water Resources Engineering

See p. 43.

University Program on Science, Technology, and Society (STS)

Of interest to many engineering students and faculty is a University-wide program dealing with the interaction of science and technology with contemporary society. Through the program a number of new research and teaching efforts in this area have been initiated. The program will sponsor courses, seminars, workshops, summer studies, and individual research programs on such topics as 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. The participation of students and faculty from all colleges and schools in the University is welcomed.

The following courses are being sponsored by the Program on Science, Technology, and Society in collaboration with various divisions of Cornell during 1970–71:

- Biology 201–202, Biology and Society (fall and spring)
- Business and Public Administration 461, Biomedical Research and Development (fall)
- Engineering 205, Social Implications of Technology (fall); (See p. 141 for course description.)
- Government 515, Impact of Technology on Foreign Defense and Disarmament Policies (fall)
- Center for International Studies 561, International Flows of Science and Technology (fall)

A list of other relevant courses and further information may be obtained from the Program Office, 632 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 science, 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 adviser 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 first digits of the four-digit course numbers have significance as follows:*

1000	THEORETICAL AND APPLIED MECHANICS
2000	CIVIL ENGINEERING
2300, 2500	Water Resources Engineering (see Civil Engineering)
2400	Geotechnical Engineering (see Civil Engineering)
2600	Environmental Systems Engineering (see Civil Engineering)
2700	Structural Engineering (see Civil Engineering)
3000	MECHANICAL ENGINEERING
3300, 3400	Mechanical Systems and Design (see Mechanical Engineering)
3600	Thermal Engineering (see Mechanical Engineering)
4000	ELECTRICAL ENGINEERING
5000	CHEMICAL ENGINEERING
6000	MATERIALS SCIENCE AND ENGINEERING
7000	AEROSPACE ENGINEERING
8000	ENGINEERING PHYSICS
8000	Applied Physics
8300	Nuclear Science and Engineering
9000	INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH
three-digit numbers	AGRICULTURAL ENGINEERING BASIC STUDIES COMPUTER SCIENCE

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. 7, Oct. 28, Nov. 18, Dec. 9.

Plane analytic geometry, differential and integral calculus, and applications.

192 Calculus for Engineers (u). Either term. Credit four hours. Prerequisite, 191 or 193. Fall term: M W F S 9:05, 11:15. Spring term: 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. 17, Mar. 10, Apr. 7, May 5.

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. 7, Oct. 28, Nov. 18, Dec. 9.

Covers contents of 191, giving 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. 17, Mar. 10, Apr. 7, May 5.

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. Fall term: lectures, M W F 8, 12:20 plus recitation periods to be arranged. Spring term: M W F S, 9:05, 11:15. 293H is an Honors section in the fall term only. (Preliminary examinations: Oct. 13, Nov. 10, and Dec. 8 at 7:30 p.m.)

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. Fall term: M W F 8, 12:20. Spring term: lectures, M W 8, 12:20 plus recitation periods to be arranged. 294H is an Honors section in the spring term only. (Preliminary examinations: Mar. 2, Mar. 23, and May 5 at 7:30 p.m.)

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, F 9:05 or 11:15. Three discussion periods per week and one two-hour laboratory period every other week, as assigned. Preliminary examinations will be held at 7:30 p.m. on Oct. 13, Nov. 17, Mar. 2, and April 20. Primarily for students of engineering and for prospective majors in physics. Fall term, Mr. Newhall 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. Prerequisites, Physics 112 and Mathematics 192 or 112, or consent of instructor. Lectures T Th 9:05 or 11:15. Two discussion periods per week, as assigned. Preliminary examinations will be held at 7:30 p.m. on Mar. 8 and Apr. 19. Primarily for students of engineering and for prospective majors in physics. 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). Spring. Credit one hour. Prerequisite, coregistration in Physics 213. One two-hour period every week, as assigned. Mr. Richardson and staff.

Experiments include electrical measurements and circuits, and physical electronics.

[**214 Physics III: Optics, Waves, and Particles (u).** Either term. Credit three hours. Prerequisites, Physics 213 and Mathematics

293 or 221, or consent of instructor. To be given for the first time in the fall 1971. Primarily for students of engineering and for prospective majors in physics.

Wave phenomena, physical optics, waves and particles, theory of atoms. At the level of *Fundamentals of Optics and Modern Physics,* 1968, by Hugh D. Young.]

[214L Laboratory to Accompany Physics 214 (u). Either term. Credit one hour. Prerequisite, coregistration in Physics 214. One two-hour period, as assigned. To be given for the first time in the fall 1971.]

217 Physics II: Electricity and Magnetism (u). Spring. Credit four hours. An Honors section of 213–213L. Prerequisites, same as for 213, and in addition (a) a request for this course as expressed by the student in consultation with the 217 instructor and, for an engineering student, with the concurrence of the director of the Division of Basic Studies in the College of Engineering; and (b) an invitation from the instructor. Enrollment limited. T Th S 11:15 and one laboratory every week, as arranged. Mr. Pohl and staff.

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). Either term. Credit four hours. An honors section of 214. Same conditions govern enrollment as for 217. To be given for the first time in the fall 1971.]

233–234 Introductory Analytical Physics III and IV (u). Fall and spring. Credit three hours a term. (Physics 233 is also offered in the spring term, T Th S 11:15, for those students who failed the course in the preceding fall term but who passed Physics 235.) Prerequisites, Physics 122 and coregistration in Mathematics 293–294 and in Physics 235–236, or consent of the instructor. Course 233 is prerequisite to 234. Lectures, T Th 9:05 or 11:15. Two discussion periods every week to be arranged. Each term the course is subdivided into two independent sections, each of no more than 270 students (and for each lecture, no more than 135 students). Preliminary examinations will be held at 7:30 p.m. on Oct. 8, Nov. 5, Dec. 10, Feb. 18, Mar. 18, April 22. Fall term, Messrs. Gittelman, Richardson, and staff; spring term, Messrs. Orear, Littauer, and staff.

Electrostatic fields, potential, fields around conductors and in simple dielectrics, special relativity, charges in motion, time-varying fields, induced electromotive force, energy of charge and current distributions, electrical oscillations and oscillatory behavior in general, electromagnetic waves, polarization, interference and diffraction. Quantum effects, atomic and x-ray spectra, nuclear structure and reactions, particle physics, and solid state physics. At the level of *Electricity and Magnetism,* 1966, by Purcell (Berkeley Physics Course, Vol. 2); of *Introduction to Special Relativity,* 1965, by Smith; and of *Fundamentals of Optics and Modern Physics,* 1968, by Young.

235–236 Laboratory to Accompany Physics 233–234 (u). Fall and spring. Credit one hour a term. Must be taken with Physics 233–234. Course 235 is prerequisite to 236. One two-hour period every week to be arranged. Messrs. Lee, Richardson, and staff.

Experiments include electrical measurements, circuits, physical electronics, optics, lasers, atomic spectroscopy, solid state, nuclear, and particle physics.

237–238 Introductory Analytical Physics III and IV (u). Credit four hours a term. An Honors section of 233–234 *and* 235–236. Prerequisites, same as for 233–234 and 235–236, and in addition (a) a request for this course as expressed by the student in consultation with the 237 instructor and, for an engineering student, with the concurrence of the director of the Division of Basic Studies in the College of Engineering, and (b) an invitation from the instructor. Enrollment limited. Course 237, or consent of the instructor, is prerequisite to 238. T Th S 9:05 or 11:15 and one laboratory every week, M T W Th or F 2–4:25. Mr. Berkelman and staff.

Topics include those (none omitted) in Physics 233–234 but their treatment is generally more analytical and somewhat more intensive. At the level of *Electricity and Magnetism,* 1966, by Purcell (Berkeley Physics Course, Vol. 2); of *Spacetime Physics,* 1966, by Taylor and Wheeler; and of *Fundamentals of Optics and Modern Physics,* 1968, by Young.

Chemistry

107–108 General Chemistry (u). Fall: credit three hours. Spring: credit four hours. Prerequisite, high school chemistry; 107 is prerequisite to 108. Enrollment is limited. Recommended for those students who will take further courses in chemistry. 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. Scheduled preliminary examinations may be held in the evening. Fall term, Messrs. Kostiner, Scholer, and staff; spring term, Mr. Burlitch and staff.

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

Chemistry Area

(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.

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.

Mathematics Area

9160 Introductory Engineering Probability (u). Spring only in 1970–71; thereafter, both terms. Credit three hours. Two lectures, one recitation. Prerequisite, first year calculus.

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, and other distributions and how they arise in practice; Markov chains and applications.

9170 Basic Engineering Statistics (u). Fall only in 1970–71; thereafter, both terms. Credit three hours. Two lectures, one recitation. Prerequisite, first year calculus.

At the end of this course a student should command a working knowledge of basic statistics. For many students this will be the only course in statistics they will ever take. Students who wish to learn more about statistics should take a course in probability, like 9360, next. The topics introduced in the course include: 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 of 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, 201 or some programming experience in an algebraic language. M W F 9:05.

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.

Mechanics and Materials Area

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 *Engineering Science Mechanics*, by Long.

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.

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.

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 *Engineering Mechanics*, by Shames.

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.

Physics and Electricity Area

4210 Introduction to Electrical Systems (u). Either term. Credit three hours. Three lecture-recitations. Prerequisites, Mathematics 192 and Physics 122.

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).

8117 Contemporary Topics in Applied Physics (u). Spring. Credit three hours. The course will consist of lecture periods combined with recitations and some experiments. Messrs. Rostoker and Wolga.

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.

Physical Education

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 (for further details, see the *Announcement of General Information*). Descriptions of the physical education courses offered will be found in publications made available to entering students by the Department of Physical Education and Athletics.

Aerospace Engineering

7001 Introduction to Aeronautics (u,g). Fall. Credit three hours. Open to upperclass engineers and others by permission of the instructor. Messrs. George and 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 and helicopter performance, power required, etc. Elementary stability and control.

7002 Introduction to Aerospace Systems (u,g). Spring. Credit three hours. Messrs. Auer and Turcotte.

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.

7101 Advanced Kinetic Theory (g). Fall. Credit three hours. Mr. de Boer.

The Boltzmann equation. Solution for gas in equilibrium. Collision frequency and mean free path calculations. Conservation equations. Hilbert-Enskog-Chapman theory of transport coefficients. Grad's thirteen moment equations. The BGK equation. The BBGKY theory.

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. Mr. Shen.

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. Mr. de Boer.

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. Mr. Auer.

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. George.

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. Credit three hours. Mr. George or 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. Prerequisites, 7301, 7302.

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. Credit three hours. Prerequisites, 7301, 7302. Mr. George or 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 Current Topics in Fluid Mechanics (g). Either term. Credit three hours.

Current topics relating to present engineering practice and/or research interests of the faculty and staff.

7307 Acoustics and Aerodynamic Noise (g). Either term. Credit three hours. Mr. George.

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 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. CUPL 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, Engineering 3331 or the equivalent. Mr. Gunkel.

The principles of design and development of agricultural machines to meet functional requirements. Emphasis is given to computer-aided analysis and design, stress analysis, selection of construction materials, and testing procedures involved in agricultural machine development.

[**462 Agricultural Power (u,g).** Fall. Credit three hours. Two lectures, one laboratory, and computing periods. Prerequisite, Engineering 212 or the equivalent. Not offered in 1970–71.

Basic theory, analysis, and testing of internal combustion engines specifically for use in farm tractors and other agricultural power applications. Tractor transmissions, Nebraska Tractor Tests, soil mechanics related to traction stability, shop dynamometers, fuels, hydraulic equipment.]

463 Processing and Handling Systems for Agricultural Materials (u,g). Spring. Credit four hours. Three lectures, one laboratory. Prerequisite, Engineering 212 or the equivalent. Mr. Furry.

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 program in CUPL.

[**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. Not offered in 1970–71. 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. Prerequisites, Engineering 2701 and 3621. Not offered in 1970–71. 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 (CE 2432) (u,g). Offered upon sufficient demand, usually in the fall. 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 Engineering (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 program in FORTRAN, although knowledge of CUPL is acceptable.

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, signal conditioning, shielding and grounding; transducers for measurement of force, pressure, displacement, velocity, acceleration, temperature, humidity, and flow; and data acquisition systems, including telemetry.

504 Biological Engineering Analysis (g). Fall. Credit four hours. Three lectures. Prerequisite, consent of instructor or Engineering 1151. Mr. Cooke.

Engineering problem-solving techniques will be treated. Particular attention will be given to the formulation of biological problems in an engineering context. Experience will be gained in problem definition, mathematical formulation, and interpretation of results. Principles of feedback control theory will be studied and applied to biological systems.

505 Solid Waste Management (u,g). Spring. Credit three hours. Prerequisite, permission of instructor. Mr. Loehr.

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 Management (CE 2531) (u,g). Spring. Credit three hours. Prerequisite, permission of instructor. Mr. Loehr. Not offered in 1970–71.

Legal aspects; assimilatory capacity of receiving waters; waste sampling and analysis; good housekeeping; treatment processes; waste reduction possibilities; waste quantity and quality, reuse and recovery; joint industry-municipal treatment of wastes; sewerage service charges; case studies. Intended primarily for graduate students but open to qualified undergraduates.]

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 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. Messrs. Rostoker and Wolga.

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.

8121 Thermodynamics and Fluid Mechanics (u). Fall. Credit three hours. Mr. Resler.

Classical thermodynamics and applications; compressible, one-dimensional flows and shock waves; introduction to fluid mechanics. The general level of sophistication expected in 8121–8122 is that of the fourth-year student in engineering physics.

8122 Statistical Mechanics and Kinetic Theory (u). Spring. Credit three hours. Prerequisite, 8121 or equivalent. Mr. Webb.

Ensembles and partition functions, ideal quantum and classical gases, imperfect gases, distribution and correlation functions. Random walks and Brownian motion, fluctuations, kinetic theory. At the level of *Fundamentals of Statistical and Thermal Physics,* by F. Reif.

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 law; 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.

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. Prerequisites, 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. Prerequisites, 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.

8205 Electrical and Magnetic Properties of Engineering Materials (g). Fall. Credit three hours. (Same as 6605.) 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). Fall. Credit three hours. Offered jointly with the Department of Materials Science and Engineering. 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). Spring. Credit three hours. Three lectures. Prerequisite, 8211. Offered jointly with the Department of Materials Science and Engineering. 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 (same as Electrical Engineering 4661) (g). Spring. Credit three hours. Three lectures. Prerequisite, Physics 561, 562 or permission of instructor. Mr. Liboff.

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). Spring. Credit three hours. A lecture course for graduate students and upperclassmen offered jointly with the Department of Materials Science and Engineering (6762). 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.

8303 Introduction to Nuclear Science and Engineering (u,g). Fall. Credit three hours. Mr. Kostroun.

A lecture and seminar course providing an introduction to nuclear engineering and low-energy nuclear physics for qualified juniors, seniors, and graduate students majoring in subjects other than nuclear science or nuclear engineering. The objective is to relate the experience of students in other fields to nuclear science and engineering. Topics include: systematics of nuclear structure; properties of nuclear radiations; nuclear fission and the neutron chain reaction; the classification and uses of nuclear reactors.

8309 Low-Energy Nuclear Physics (u,g). Spring. Credit four hours. Three lectures. Prerequisite, an introductory course in atomic and nuclear physics including quantum mechanics. Mr. McPherson.

Low-energy nuclear physics as an organized body of experimental facts. Properties of ground and excited states of nuclei; models of nuclear structure; low-energy nuclear reactions—scattering, absorption, fission, resonance effects, coherent scattering effects. At a level between *Introductory Nuclear Physics,* by Halliday, and *Nuclear Physics,* by Fermi.

[**8310 Nuclear Structure Physics (g).** Fall. Credit three hours. Three lectures. Prerequisite, 8309 or Physics 572. Not offered in 1970–71.

Nuclear models, reactions, and decay processes. Emphasis is on nuclear symmetry properties and recent trends in model calculations. At the level of *Physics of the Nucleus,* by Preston.]

8312 Nuclear Reactor Theory I (g). Fall. Credit four hours. Three lectures. Prerequisites, one year of advanced calculus and an introductory course in atomic and nuclear physics. Mr. Clark.

The physical processes in neutron chain reactors are described. The theory of neutron diffusion and slowing down is developed and applied to these processes. Neutron transport theory is introduced at the level of *Nuclear Reactor Theory,* by Lamarsh.

8313 Nuclear Reactor Theory II (g). Spring. Credit three hours. Three lectures. Mr. Cady.

Continuation of 8312 primarily intended for students planning to do research in the fields of reactor physics and reactor engineering. Delayed neutron kinetics, fission product poisoning, nonlinear kinetics, perturbation theory, temperature coefficients, control rod theory, hydrogenous reactors, neutron transport, and heterogeneous reactor theory. At the level of *The Physical Theory of Neutron Chain Reactors,* by Weinberg and Wigner.

8314 Neutron Transport Theory (g). Spring. Credit three hours. Three lectures. Prerequisite, 8312 or consent of instructor. Mr. Nelkin.

The linear Boltzmann equation describing neutron migration in matter is intensively studied. Topics will vary, but may include Milne's problem, neutron thermalization, deep penetration of radiation, as well as a formal development of approximate methods of solution. At the level of *Neutron Transport Theory,* by Davison. Offered in alternate years.

8333 Nuclear Reactor Engineering (g). Fall. Credit four hours. Three lectures. Prerequisite, consent of instructor. Mr. Cady.

A selected set of topics representing the fundamentals of nuclear reactor engineering; energy conversion and power plant thermodynamics, fluid flow and heat transfer, thermal stresses, radiation protection and shielding, materials for nuclear reactors, economics of nuclear power and fuel cycles, instrumentation and control. 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 conceptual design study of a nuclear reactor system. Emphasis is on the interplay of requirements of safety and economics 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. 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. 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. Prerequisites, 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 Introduction to the Physics of Atoms and Molecules (u,g). Spring. Credit three hours. Prerequisite, Physics 443, Chemistry 593, or consent of instructor. Mr. Fleischmann.

A semiquantitative introduction to modern physics of atomic and molecular processes including atomic and molecular structure and spectra, resonance processes, elastic and inelastic collisions, ionization and recombination.

[**8512 Electron Microscopy and Diffraction (g).** Spring. Credit three hours. Mr. Silcox. Not offered in 1970–71.

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 Physical Approaches to Problems of Photosynthesis (u,g). Fall. Credit three hours. (Same as Biological Sciences 545.) Prerequisites, Chemistry 104 or 108, Mathematics 112, Physics 208, or permission of the instructor. M 1:25, T Th 10:10. Mr. Clayton.

Emphasis is on physical and photochemical mechanisms and physical experimental approaches. Photosynthetic organisms; their photochemical apparatus, metabolic pathways, and mechanisms for energy conversion. Descriptive introduction to the physics of excited states in molecules and molecular aggregates. Optical and photochemical properties of chlorophyll and of the living photosynthetic tissue. Contemporary investigations of the photosynthetic mechanism. The level of the course can be judged by consulting *Molecular Physics in Photosynthesis,* by R. K.

Clayton (Blaisdell Publishing Co., Waltham, Mass., 1965).

[8603 **General Photobiology (u,g).** Fall. Credit three hours (same as Biological Sciences 547). Prerequisites same as for Biological Sciences 545. M 1:25, T Th 10:10. Not offered in 1970–71. Mr. Clayton.

A survey of systems of current interest in photobiology, including photosynthesis, bioluminescence, vision, photoperiodism, and the action of ultraviolet on nucleic acids. Physical concepts and methodologies are emphasized.]

Chemical Engineering

5041 Nonresident Lectures (u). Fall. One lecture. Mr. 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. Mr. Watt.

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. Credit three hours. Two lectures, one computing. Parallel, Physical Chemistry 287. 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). Spring. Credit three hours. Two lectures, one computing. Parallel, Physical Chemistry 288. Mr. Thorpe.

Phase equilibria and phase diagrams. The equilibrium stage; mathematical description of single and multistage operations; analytical and graphical solutions.

5103 Chemical Engineering Thermodynamics (u). Spring. Credit three hours. Three lectures. Prerequisites, 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). Fall. Credit three hours. Three lectures. Prerequisite, 5304. Mr. Finn.

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 nonideal flow on reactor performance. Optimum design for complex reactions. Analysis of current literature on topics such as partial oxidation, catalytic cracking, hydrogenation, and polymerization.

5108 Colloidal and Surface Phenomena (g). Fall. Credit three hours. Prerequisite, physical chemistry. Mr. Finn.

Lectures, demonstrations, and problems in the physics and chemistry of small particles and surface films. Topics include surface energy, surface films, electrokinetics, and colloidal behavior.

5109 Advanced Chemical Kinetics (g). Spring. Credit three hours. Three lectures. Prerequisite, 5106 or equivalent. Mr. Watt.

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). Spring. Credit three hours. Three lectures. Prerequisite, physical chemistry. Mr. Thorpe.

A detailed study of the pressure-temperature-composition relations in binary and multicomponent heterogeneous systems where several phases are of variable composition. Prediction of phase data.

5203 Chemical Processes (u). Spring. Credit four hours. Four lectures. Mr. Wiegandt.

An analysis of important chemical processes and industries.

5205 Chemical Process Seminar (g). Fall. Credit two hours. Mr. Wiegandt.

A discussion of recent advances in chemical process development.

5256 Materials (u). Fall. Credit three hours. Three lectures. Prerequisites, 5101, 5102, Chemistry 287, 288. Mr. Cocks.

An introductory presentation of the nature, properties, treatment, and applications of the more important metals and alloys, including extractive and physical metallurgy and behavior under service conditions. Nonmetallic materials, including refractories and cement, are also discussed.

5257 Materials (u). Fall. Credit five hours. Three lectures, two laboratories. Lectures same as in 5256. Mr. Cocks.

Laboratory includes elements of chemical microscopy, crystallography, and the microscopic characterization of materials.

5303 Analysis of Separation Processes (u). Spring. Credit three hours. Three lectures, one computing. Prerequisites, 5304, familiarity with CUPL, the Cornell computing language. Mr. Watt.

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.

5304 Introduction to Rate Processes (u). Fall. Credit three hours. Three lectures, one computing. Prerequisite, 5102. Mr. Watt.

An introduction to fluid mechanics, heat, and mass transfer.

5312 New Separation Techniques (g). Fall. Credit three hours. Three lectures. Mr. Edwards.

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. Edwards, Harriott, Smith, Von Berg, and Winding.

Laboratory experiments in fluid dynamics, heat transfer, and mass transfer. Correlation and interpretation of data. Technical report writing.

5354 Project Laboratory (u). Spring. Credit three hours. Prerequisite, 5353. Messrs. Harriott and Watt.

Soecial laboratory projects involving bench-scale or pilot-plant equipment.

5505, 5506 Advanced Transport Phenomena (g). Fall and soring. Credit four hours. Messrs. Harriott, Smith, 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.

5510 Numerical Methods in Chemical Engineering I (g). Fall. Credit three hours. Two lectures, one computing. Mr. Leinroth.

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. Prerequisite, 5510. Mr. Leinroth.

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.

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. Prerequisites, 5104, 5204, 5304. Mr. York.

Methods for estimating capital and operating costs. Performances, 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. Mr. York.

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.

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 1970–71.

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. Prerequisites, 5621, 5622, 5641. Not offered in 1970–71.

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.

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. Rodriguez.

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.

[**5745 Analysis of Polymeric Processes (g).** Fall. Credit three hours. Three lectures. Prerequisite, 5256 or 5742. Not offered in 1970–71.

Technical and economic evaluations of the principal processes used in manufacture of resins, plastics, and elastomers, including analysis of raw materials, reactor systems, product preparation, and problems in distribution and marketing.]

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 (g). Spring. Credit three hours. Two lectures, one recitation. Prerequisites or parallel courses, Chemistry 288 and any course in microbiology.

An advanced discussion of fermentation as a unit process. Topics include sterilization, aeration, agitation, and continuous fermentation.

5749 Industrial Microorganisms (g). Fall. Credit one hour. One lecture. Prerequisites, 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). Fall. 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). Fall. 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). Either term. 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, facilitated transport in membranes, and the artificial kidney.

5790 Consumer Products Engineering (same as Industrial Engineering and Operations Research 9514) (u,g). Fall. Credit three hours. Two lectures, one computing. 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. Prerequisites or parallel courses, physical chemistry, e.g., Chemistry 287, 288, or 389, 390, and Physics 233, 234 or special permission. Mr. Cocks.

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). Fall. Credit three hours. One lecture, two laboratory. Prerequisite, 5851 or special permission. Mr. Cocks.

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 Engineering

General

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 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 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 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.

Environmental Systems Engineering

In addition to the courses listed below, other courses offered throughout the University may be selected to support studies in the general subject area of environmental systems engineering. See especially the offerings listed elsewhere in this *Announcement* under Civil Engineering and Operations Research as well as those of City and Regional Planning (College of Architecture, Art and Planning), Business and Public Administration and Economics (College of Arts and Sciences).

201 Microeconomic Analysis (u). Fall. Credit three hours. M W F 10:10. Prerequisite, one year of college-level mathematics. Mr. Falkson.

Topics include the theory of the firm, production, market structures, consumer behavior, and welfare economics. May not be taken for credit in addition to Economics 102.

202 Macroeconomic Analysis (u). Spring. Credit three hours. M W F 10:10. Prerequisite, 201. Mr. Falkson.

Topics include the theory of international trade, national income determination, economic growth and stability, and monetary and fiscal policy. May not be taken for credit in addition to Economics 101.

301 Microeconomic Analysis (g). Fall. Credit three hours. Mr. Falkson.

An introduction to microeconomic analysis for graduate students. The same lectures are offered as in 201, but there is a more intensive reading list.

302 Macroeconomic Analysis (g). Spring. Credit three hours. Mr. Falkson.

An introduction to macroeconomic analysis for graduate students. The same lectures are offered as in 202, but there is a more intensive reading list.

2601 Transportation Engineering (u). Fall. Credit three hours. Two lectures, one recitation. 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.

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.

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.

2611 Economics of Environmental Quality Management (g). On demand. Credit one to four hours. Prerequisites, Economics 510–511 and permission of instructor. Mr. Falkson.

A graduate seminar devoted to theoretical welfare economics and its application to the management of environmental quality.

2612 Applied Welfare Economics (g). On demand. Credit one to four hours. Prerequisite, permission of instructor. Mr. Falkson.

This seminar is an extension of 2611 with substantially greater emphasis on the application of welfare economcs, statistics, and system analysis to public investment decisions in areas such as water resources, transportation, and public health.

2617 Environmental Systems Analysis I (g). Fall. Credit one-three hours at Department's option. Three lectures. Prerequisite, permission of instructor. Messrs. ReVelle and Stidham. Intended for graduate students but open to qualified undergraduates.

Structuring and solution of mathematical programming models with emphasis on linear programming and its extensions. Introduction to Lagrange multipliers, network theory, dynamic programming, nonlinear programming. Application of systems analysis techniques to the solution of complex environmental, engineering-economic problems.

2618 Environmental Systems Analysis II (g). Spring. Credit three hours. Three lectures. Prerequisites, 2617 and 9160 or equivalent and permission of instructor. Messrs. ReVelle and Stidham.

Advanced topics in the application of mathematics programming and probability theory to the solution of environmental engineering problems.

[**2619 Location Analysis (g).** Fall. Credit three hours. Next offered 1971–72. Prerequisite: 2617 or equivalent. Mr. ReVelle.

Location objectives and constraints. Euclidean location. Network location. The private sector problem: plant location, heuristic and exact approaches, relation to public sector problems. The public sector problem: p-median problem, heuristic and exact approaches, the minimum-maximum time formulation. Students are required to do a project in location analysis.]

2621 Theory of Traffic Flow (g). (Also listed as Operation Research 9527.) Spring. Credit three hours. T Th 11:15–12:30. Prerequisites, 9360 or permission of instructor. Mr. Stidham.

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.

2622 Transportation Systems Analysis (g). Spring. Credit three hours. Prerequisite, 301, 9360, and 2617 or 9522 or equivalents. Mr. Meyburg.

Techniques of systems analysis are applied to physical planning, operating, 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.

2623 Urban Transportation Planning (g). Fall. Credit three hours. Prerequisites, 2601 or permission of instructor. Mr. Meyburg.

The urban transportation problem. The urban transportation planning process; demand analysis; transportation planning models. Interaction of urban and regional transportation systems. Present and future transport modes. Predictability of demand for new modes. Analysis of economic and social impact.

[2626 Traffic Engineering (u). Fall. Credit three hours. Two lectures, one laboratory. Prerequisite, permission of instructor. Not offered in 1970–71.

City and highway traffic surveys and designs. Accidents, congestion, delay, speed, volume, density, parking, channelization, lighting, traffic control, and routing. Signs, signals, and markings. Urban traffic consideration in city planning. Driver reactions and habit patterns. Traffic engineering organization.]

2628 Airport Planning and Operations (g). Spring. Credit three hours. Prerequisite, 2623. 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.

[2631 Construction Management (g). Fall. Credit three hours. Prerequisite, permission of instructor. Not offered in 1970–71.

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, 2617 or consent of instructor. Mr. Lynn.

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.

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 Environmental Systems Design Project (g). On demand. Credit variable. Prerequisite, permission of instructor. May extend over two semesters. Staff.

Design of feasibility study of environmental systems, supervised and assisted by one or more faculty advisers. Individual or group participation. Final report required.

2692 Environmental Systems Engineering Research (g). On demand. Credit variable. Prerequisite, permission of the instructor. Staff. Preparation must be suitable to the investigation to be undertaken.

Investigation in depth of particular environmental systems problems.

2693 Environmental Systems Engineering Colloquium (g). Either term. Credit one to two hours. Required of all graduate students with a major or minor in environmental systems engineering. Open to advanced undergraduates by permission of instructor. Staff and distinguished visiting lecturers.

Preparation, presentation, and informal discussion of topics concerned with environmental systems.

2694, 2695 Special Topics in Environmental Systems Engineering (g). On demand. Credit variable. Staff.

Supervised study by individuals or small groups in one or more specialized topics not covered in regular courses.

Geotechnical Engineering

Soil Mechanics and Foundation Engineering; Subgrades and Pavements

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 Foundation Engineering (u,g). Spring. Credit three hours. Three lectures. Prerequisite, 2401. Mr. Sangrey.

Principles of bearing capacity and deformation theory; stress distribution; shallow and deep foundations; prediction of settlement; design of footing, raft, caisson, and pile foundations. Problems of construction; support of excavations; ground water lowering. Foundation investigations.

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; soil classification; principle of effective stress; shear strength and compressibility of saturated and partly saturated soils; sensitivity; effects of anisotropic consolidation; permeability; laboratory and field tests.

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 Earth Pressure and Seepage (u,g). Fall. Credit three hours. Three lectures. Prerequisite, 2401. Mr. Sangrey.

Mechanics of the development of earth pressure in relation to soil properties and the imposed deformation conditions. Effects of seepage on the development of earth pressure. Design and stability of bulkheads and cofferdams. Pressures on shafts, tunnels, and conduits. Steady and transient flow of fluids through compressible and incompressible porous media. Consolidation processes. Sand drains. Field determination of permeability. Flow nets and the modification of flow patterns by drains and relief wells.

2416 Slope Stability; Earth and Rock-Fill Dams (u,g). Spring. Credit three hours. Three lectures. 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 rock-fill 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.

Aerial Photographic Studies and Physical Environment Evaluation

[**2421 Physical Environment Evaluation (u,g).** Fall. Credit three hours. Two lectures, one laboratory. Intended for graduate students or upperclassmen in engineering and planning. Prerequisite, permission of the instructor. Not offered in 1970–71.

A study of physical environment factors affecting engineering and planning decisions and the evaluation methods of these factors. Physical factors include the climate, soil and rock conditions, and water resources in different parts of the world. Evaluaton methods include field reconnaissance; interpretation of meteorological, topographic, geological, and soil maps; aerial photography; engineering data; and subsurface exploration records.]

[**2422 Advanced Physical Environment Evaluation (u,g).** Spring. Credit three hours. Two lectures, one laboratory. Intended for graduate students or upperclassmen in engineering or planning. Prerequisite, 2421 or 2423 or permission of instructor. Not offered in 1970–71.

A study of physical environment by use of airphotos and other remote-sensing methods.

Conventional photography, sequential photography, multiple spectral photography, space photography, infrared thermal and radar imageries are included in the study. Evaluation of environment is directed to the planning of engineering and development projects in general, with some emphasis on those related to special climatic regions such as tropical humid and arid regions.]

2423 Analyses and Interpretation of Aerial Photographs (u,g). Fall and spring. Credit three hours. Preregistration required. Two lectures, one laboratory. (The student is expected to pay the cost of field trips and aerial photographs for use in a term project, amounting to approximately $15.) Mr. Belcher.

Methods of identification of a broad spectrum of soils, rocks, and drainage conditions as well as the significance of vegetative and cultural patterns of the world. Natural resources inventories and specific fields of application are emphasized.

2424 Advanced Interpretation of Aerial Photographs (u,g). Fall and spring. Credit three hours. Preregistration required. Mr. Belcher.

Course includes lectures and team projects in laboratory and field. Facilities include material for city-regional planning, soil mapping, conservation, ground and surface water, and civil engineering projects.

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 (Agricultural Engineering 491) (u,g). On 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.

Geodetic and Photogrammetric Engineering

2451 Surveying (u). Spring. Credit three hours. Two lectures, one laboratory. Prerequisite, 9170 or permission of instructor. Mr. Lyon.

Study of basic surveying instruments and procedures for measuring and laying out angles, distances, areas, and volumes; data processing and presentation of results of measurement operations; geometric geodesy; photogrammetry; field astronomy; graphical and numerical representation of topography; and planning and specifications for surveying operations.

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. Laboratory 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: propagation of electromagnetic waves, hyperbolic navigation systems, ranging and azimuthal navigation systems.

2461 Elementary Geodesy (u,g). Fall. Credit three hours. Three lectures. Mr. McNair.

Principal problems of geodesy. Coordinate systems; reference datum. Geometric problems on earth ellipsoid. Application of Bjerhammar singular matrix calculus; singular matrices to geodesy.

2462 Geophysical Geodesy (u,g). Spring. Credit three hours. Three lectures. Mr. McNair.

Basic potential theory, Laplace and Poisson equations; 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.

2463 Geodetic Control Surveys (u,g). Credit three hours. Two lectures, one laboratory. Prerequisite, 2451 or 2461. Mr. McNair.

Principles of establishing a geodetic sea-level datum; isostasy, the geoid and ellipsoid; altimetry, trigonometric, spirit, and electronic leveling; orthometric and dynamic heights; electronic distance measurement; triangulation and trilateration; design of control networks and systems; astronomic and gravimetric observations, and satellite triangulation.

2464 Geodetic Astronomy (u,g). Credit two hours. Two lectures. Prerequisite, 2451 or equivalent work in field astronomy. Mr. Lyon.

Study of the precise determination of latitude, longitude, and azimuth from astronomical observations. Night observation periods.

2465 Errors and Adjustments of Surveys (u,g). Fall. Credit three hours. Prerequisites, laboratory work involving physical measurements, Mathematics 293 or permission of instructor. Mr. Lyon.

Measurement systems; analysis of errors and of error propagation; application of the principles of probability to the results of measurements for the purpose of determining the best estimates of measured and deduced quantities and the best estimate of uncertainty in these quantities; adjustment of conditioned measurements by the method of least squares and other methods; curve fitting.

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.

2471 Elements of Photogrammetry (u,g). Fall. Credit three hours. Two lectures, one laboratory. Mr. McNair.

Principles and practice of terrestrial and aerial photogrammetry including flight planning, control requirements, geometry of a photograph, simple stereoplotting instruments, parallax distortions, mosaics and orthophotos, semigraphical and analytical tilt determination. Charting from space photography. A three-projector Balplex double-projection stereoplotter is used for basic mapping instruction.

2472 Advanced Photogrammetry (u,g). On demand. Credit three hours. Two lectures, one laboratory. Prerequisite, 2471. Mr. McNair.

An advanced study of photogrammetric principles including rectification, graphical and instrumental aerotriangulation, mapping from space photography, and geometry of remote sensors. A first-order Wild A-9 autograph is used for aerial mapping instruction. A Zeiss stereometric camera and terragraph plotter are used for terrestrial mapping and for nontopographic, metric, and documentation problems.

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.

2481 Cadastral Surveying (u,g). On demand. Credit three hours. Three lectures. Mr. Lyon.

Study of legal principles and surveying operations associated with acquisition of evidence for the delineation of boundaries of real estate. Topics covered include metes and bounds, subdivision, and other methods of description of real property; land courts; riparian rights; mineral rights; resurveys; and authority and responsibilities of the Cadastral surveyor.

2482 Engineering Surveys (u,g). Spring. Credit three hours. One lecture, two laboratories. Prerequisite, 2451 or equivalent. Mr. Lyon.

Circular curves, transition curves, earthwork measurement and calculation, topographic surveys, construction surveys, and project planning from maps.

General

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.

Structural Engineering

2701 Structural Engineering I (u). Fall. Credit three hours. Two lectures, one two-hour period. Prerequisite, Mechanics 212. Evening preliminary examinations. Staff.

First course in a four-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. Deflections by moment-area method. Approximate analysis of frames and beams.

2702 Structural Engineering II (u). Spring. Credit three hours. Two lectures, one two-hour period. Prerequisite, 2701 and coregistration in 2751. Evening preliminary examinations. Staff.

Deflections and analysis of indeterminate structures by method of virtual work. Cable structures and prestressing concepts. Properties and behavior of reinforced concrete. Behavior under load of reinforced concrete beams, columns, and beam columns.

2703 Structural Engineering III (u). Fall. Credit three hours. Two lectures, one two-hour period. Prerequisites, 2702, 2751. Staff.

Continuation of indeterminate analysis topics of Civil Engineering 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.

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 postbuckling 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. Prerequisites, 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). Fall. Credit three hours. Two lectures, 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 Numerical Methods and Probability (u,g). Spring. Credit three hours. Prerequisites, differential equatons, consent of instructor, and coregistration in Computer Science 311. Messrs. White and Sexsmith.

Numerical integration techniques. Solution of linear and nonlinear systems. Finite difference techniques for boundary value problems. Computer applications. Introduction to probability concepts pertaining to structural analysis and design. Structural reliability; inference techniques; decision theory; stochastic processes.

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, light weight structures.

2720 Shell Theory and Design (u,g). Fall. Credit three hours. Prerequisites, 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 Dynamics of Structures (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 Aerospace Structural Analysis I (u,g).** Fall. Credit three hours. Prerequisites, Mechanics 211 and 212. Not offered in 1970–71.

Evolution of aerospace structural design concepts and the structural design cycle. Environment, structural design criteria, and specifications for aircraft, missiles, and spacecraft. Inertia loads, load factors, flight envelopes, gust loads. Aerodynamic and solar heating, loads in space flight. Materials of construction and their properties; elastic and inelastic behavior; fatigue. Theories of failure. Fracture mechanics. Elementary structural analysis.]

[**2731 Aerospace Structural Analysis II (u,g).** Spring. Credit three hours. Prerequisites, Mechanics 211 and 212. Not offered in 1970–71.

Structural problems and configurations of aircraft, missiles, and spacecraft. Analysis and design of thin-walled members in bending, torsion, and combined loadings. Reinforced stressed skin construction, thick shell construction, sandwich and composite materials. Inelastic analyses: plastic and viscoelastic behavior. Buckling, torsional instability, and crippling of thin-walled beams; creep buckling. Buckling and postbuckling behavior of plates; effective width. Thermal stresses and high temperature effects.]

2732 Optimum Structural Design (g). Fall. Credit two hours. Prerequisites, 2617 or equivalent and consent of instructor. Messrs. Gallagher and Fenves.

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. Prerequisite, 6210. 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. Relationshios between 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 propertes. Applications to various engineering materials.

2757 Civil Engineering Materials Project (g). On demand. Credit one to six hours. Mr. Slate.

Individual projects involving civil engineering materials.

2758 Civil Engineering Materials Research (g). On demand. Hours and credit variable. Mr. Slate.

Individual assignments, investigations and/or experiments with civil engineering materials.

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. 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). 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.

Water Resources Engineering

Hydraulics and Hydrology

2301 Fluid Mechanics (u). Fall. Credit three hours. Three lecture-recitations. Mr. Liggett.

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.

2303 Hydrology (u,g). Fall. Credit three hours. Three lecture-recitations. Prerequisite, 2301. Mr. Brutsaert.
Introduction to hydrology including topics on precipitation, evapotranspiration, ground water, surface water, sedimentation.

2312 Experimental and Numerical Methods in Fluid Mechanics (u,g). Fall and spring. 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 and 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 (g). Spring. Credit three hours. Three recitations. Prerequisite, 2315 or permission of instructor. Mr. Liggett.
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. Theory of small amplitude waves.

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 Surface-Water Hydrology (g). Fall. Credit three hours. Prerequisite, 2301. Mr. Brutsaert.
Physical and statistical analysis relating to hydrologic processes. Hydrometeorology and evaporation. Surface runoff, base flow, and storage routing in linear and nonlinear systems. 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.

Sanitary (Environmental) Engineering and Water Resource Systems Engineering

2501 Environmental Quality Engineering (u). Spring. Credit three hours. Three lecture-recitations, field trips. Prerequisite, registration in the civil engineering undergraduate field curriculum or the College Program. Messrs. Lawrence and Loucks.
Concepts of environmental quality including ecological, economic, legal, and political 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 Environmental Quality Analysis and Evaluation (u,g). Fall. Credit three hours. One lecture, two laboratories or computings. Prerequisites, 2301 or equivalent, 2501. Mr. Behn.
Examination, analysis, and evaluation of specific environmental quality problems. Theoretical and experimental investigation of

specific environmental quality control processes and facilities. Emphasis on waste control technology and waste assimilation in water.

2503 Water Quality Engineering (u,g). Spring. Credit three hours. Two lectures, one laboratory or computing. Prerequisites, 2301, 2502, 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 Waste-Water (u,g). Fall. Credit three hours. Three lectures. Prerequisite, one year of college chemistry. Mr. Lawrence.

Principles of physical, organic, inorganic, and biochemistry applicable to the understanding, design, and control of water and waste-water 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, 2503 or equivalent and 2510. Mr. Lawrence.

Theoretical and engineering aspects of chemical and physical phenomena and processes applicable to the removal of impurities from water, waste-water, 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. Mr. Dworsky. Intended primarily for graduate engineering and nonengineering students but open to qualified undergraduates.

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. Prerequisites, 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 Health Engineering (u,g). Spring. Credit three hours. Three lecture-discussions. Prerequisite, permission of instructor. Intended primarily for graduate students in engineering. Mr. Gates.

Environmental quality concepts and objectives. Pertinent principles of ecology, epidemiology, toxicology, and radiological health. Environmental quality control methods, including air quality control, water quality control, solid waste disposal, and economic, legal, and technological aspects.

2530 Solid-Waste Management (u,g). Spring. Credit three hours. Three lectures, reports. Prerequisite, permission of the instructor. Mr. Loucks.

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 Management (u,g). Offered in alternate spring semesters. Primarily a graduate course but open to undergraduates with the permission of the instructor. Mr. Behn.

Legal aspects, assimilatory capacity of receiving waters, waste sampling and analysis, treatment processes, waste reduction possibilities, waste quantity and quality, reuse and recovery, joint industry-municipal treatment of waters, sewerage service charges, case studies.

2533 Environmental Quality Control (u,g). Fall and spring. Credit three hours. Three lecture-discussions, field trips. Prerequisite, permission of the instructor. Mr. Gates.

Introduction to environmental quality problems, their relation to man's activities, and their management; the ecological, economic, and technological aspects of air quality control, water quality control, and the control of liquid, solid, and gaseous wastes.

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 dispersion of gases and particulates in the atmosphere. Air quality effects, objectives, and standards. Air quality control 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. Prerequisites, 301, 2518 or 2618, 9360, or permission of instructor. Mr. Loucks.

Current research topics concerning the application of economic optimization 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. Prerequisites, 2501 or 2502 or equivalent. Staff.

The student will elect or be assigned problems in the design of water and waste-water treatment processes or plants; waste-water 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 Water Resources Engineering Colloquium (u,g). Fall and spring. Credit one to two hours. Required of graduate students majoring or minoring in sanitary engineering or water resources engineering. Open to undergraduates with permission of the instructor. Mr. Loucks.

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.

Computer Science

201 Survey of Computer Science (u). Fall. Credit three hours. M W F 9:05. Mr. Conway.

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, 201 or some programming experience in an algebraic language. M W F 9:05. Messrs. Morgan and Horowitz.

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.

203 Discrete Structures (u). Fall. Credit three hours. Prerequisite, 201 or 202. M W F 1:25. Mr. Wagner.

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. Prerequisites, Grade of B or better in Mathematics

122, and Computer Science 202 or 311 or consent of instructor. M W F 10:10. Mr. Baker.

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.

311 Introduction to Computer Programming (u). Either term. Credit one, two, or three hours. T Th 11:15. Mr. Blackmun.

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. Mr. Constable.

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. Messrs. Gries and Wilcox.

Characteristics and structure of digital computers as hardware units. Representation of data, complement arithmetic, floating point; addressing of data, index registers, indirect and base-plus-displacement addressing. Codes for error detection and corrections. Introduction to computer microstructure, gates, flipflops, adders. System-supplied programs, loaders, assemblers, interpreters, and compilers. Storage and peripheral hardware and their characteristics, the input-output channel, interrupts. Characteristics of operating systems.

This course is not primarily designed to teach programming, although several programs will be assigned, at least one of which is to be in machine language. Previous programming experience is helpful, but not required. The course is primarily designed for upperclassmen and graduate students who want to know more about computers than programming. Students should be warned that in using 401 as a prerequisite to further course work in the information processing area of computer science, they will be somewhat deficient in assembly language programming experience.

404 Advanced Computer Programming (g). Spring. Credit four hours. Prerequisite, 401 or consent of the instructor. T Th 1:25, F 2:30. Mr. Wagner.

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. Mr. Horowitz.

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. Mr. Williams.

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. Mr. Gries.

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, specification 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. Mr. Shaw.

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. Mr. Williams.

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. Spring. Credit four hours. Prerequisites, 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 1970–71.

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. Prerequisites, Mathematics 222 or 294 and Computer Science 311 or equivalent programming experience. M W F 10:10. Mr. Dennis.

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. Mr. Moré.

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. Mr. Jackson.

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 Hueristic Programming (g). Spring. Credit four hours. Prerequisites, 401 and 411. Not offered in 1970–71.]

485 Theory of Automata I (g). Fall. Credit four hours. Prerequisite, 203 or 401 or consent of the instructor. M W F 11:15. Mr. Constable.

Automata theory is the study of abstract computing devices; their classification, structure, and computational power. Topics include finite state automata, regular expressions, decomposition of finite automata and their realization, Turing machines and their computational power.

486 Theory of Automata II (g). Spring. Credit four hours. Prerequisite, 485 or consent of the instructor. M W F 11:15. Mr. Hartmanis.

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. M W F 2:30. Mr. Hartmanis.

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. Prerequsites, 401, 485, Mathematics 481, or consent of the instructor. T Th 10:10. Not offered in 1970–71.

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. Mr. Shaw.

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. Not offered in 1970–71.

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. Not offered in 1970–71.]

[**525 Numerical Solution of Partial Differential Equations (g).** Spring. Credit four hours. Prerequisite, 523 or consent of the instructor. M W F 11:15. Not offered in 1970–71.]

527 Introduction to Approximation Theory (g). Spring. Credit four hours. Prerequisite, 422 or consent of the instructor. M W F 10:10. Mr. Dennis.

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 1970–71.

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.]

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). Fall. Credit three hours. Prerequisites, 401 and Operations Research 9470, or consent of the instructor.

Data Processing Systems (Industrial Engineering 9582). Fall. Credit three hours. Prerequisite, 401 or consent of the instructor.

Switching Systems I (Electrical Engineering 4487). Fall. Credit three hours. Prerequisite, Electrical Engineering 4322 or consent of the instructor.

Switching Systems II (Electrical Engineering 4488). Spring. Credit three hours. Prerequisite, Electrical Engineering 4487 or the equivalent.

Electrical Engineering

Required Courses

Systems Sequence

4301–4302 Analysis of Electrical Systems I and II (u). Fall and spring. Credit four hours. Three lectures, one recitation-computing. Prerequisites, Electrical Science 242 and Mathematics 294 or equivalents. Messrs. Carlin and Szentirmai.

Analysis of linear RLC-networks; network graphs, linear independence, dimensionality. Voltage, current, and mixed bases of analysis in vector-matrix form. Network energy state, state transition, fundamental matrix, stability, excitability, observability. Forced responses; superposition integral, excitations derived from real and complex exponentials, network equilibrium state, network functions. Sinusoidal excitations; power and energy functions, properties of driving-point network functions. Analysis of linear RLC-networks with mutual inductance. Two-winding transformers. Linear models for active devices; frequency dependency, gain-bandwidth product. Analysis of linear active networks. Flow graphs; intentional feedback; sensitivity. Intentional oscillaton; conditions for instability; piecewise linear models and networks. Phase-plane analysis. Dynamical equations for mechanical and other systems. Passive and active analogs.

4401 Deterministic Signals in Linear Systems (u). Fall. Credit four hours. Three lectures, one recitation-computing. Prerequisite, 4302. Mr. Jelinek.

Fourier integral as the limiting form of Fourier series. Response of asymptotically stable linear-systems to aperiodic excitations. The Gibbs phenomenon. Convolution. Application of Fourier theory to the analysis and design of linear and pulse modulation systems. The sampling theorem. Singularity functions and initial conditions. The magnitude-phase and real-imaginary part relations for transforms of realizable systems. Nyquist criterion. Time-bandwidth relations. The Laplace Transform and its convergence properties. Analytic functions and contour integration. At the level of *The Fourier Integral and its Applications*, by Papoulis.

4402 Random Signals in Systems (u). Spring. Credit four hours. Three lectures, one recitation-computing. Prerequisite, 4401. Mr. Berger.

Description of random signals and analysis of randomly excited systems. An introduction is provided to the concepts of probability, random variables, expectation, random processes, and power spectra. Applications are drawn from the areas of communications, control, and pattern classfication. 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. Prerequisites, Physics 233 and 234 and Mathematics 294, or equivalent. Messrs. Farley and Ott.

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. Wolga.

Introduction to nonrelativistic quantum theory; experimental basis for wave-particle duality; structure of the theory in terms of wave functions and operators; solution of Schroedinger's equation for one- and three-dimensional potentials; angular momentum; spin; time-independent perturbation theory; interaction of atoms with static fields; antisymmetry and the Pauli exclusion principle; central field model of atomic structure. At the level of *Basic Quantum Mechanics*, by White.

4412 Solid State Physics and Applications (u). Spring. Credit four hours. Three lectures, one recitation. Prerequsite, 4411 or equivalent. Mr. Frey.

Introduction to solid state physics and application to electronic devices; crystal symmetry and structure; x-ray diffraction, reciprocal lattice; free electron theory, Drude theory of electrical conductivity; band theory; semiconductors and semiconductor devices including p-n junctions, transistors, avalanche and hot electron devices; lattice dynamics and dielectric properties of solids; magnetism. At the level of *Electronics of Solids*, by Beam.

Laboratory Sequence

4321 Electrical Laboratory I (u). Fall. Credit four hours. One lecture, two laboratories.

Basic electrical and electronic instrumentation and measurements involving circuits and fields of both active and passive elements; an experimental introduction to solid state and high-vacuum devices.

4322 Electrical Laboratory II (u). Spring. Credit four hours. One lecture, two laboratories.

Basic experiments concerning transmission lines, high-frequency measurements and techniques, solid state amplifiers and oscillators, and nonlinear and negative-resistance devices. Experiments illustrating the use of the digital computer in electrical engineering problems, involving a laboratory computer for online processing of measurements and a remote interactive terminal for experimental use of numerical computation techniques.

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. Spring. Credit three hours. Three lectures. Prerequisite, 4401 or Biology 423 or Physics 360 or equivalent. Messrs. Capranica and Kim.

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.

4503 Theory of Linear Systems (g). Fall. Credit four hours. Three lectures. Prerequisite, 4401 or consent of instructor. Mr. Szentirmai.

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 *Linear Systems*, by Schwartz and Friedland.

4504 Theory of Nonlinear Systems (g). Spring. Credit four hours. Three lectures. Prerequisite, 4503, 4501, 4571 or consent of instructor. Mr. Thorp.

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; perturbaton 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 aproach 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. Open to qualified seniors. Mr. Ku.

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. Ku.

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 equalizers. Rc-lines. Gain-bandwidth theory of active devices. Synthesis of active networks.

Electromagnetic Theory

4511 Electrodynamics (g). Fall. Credit four hours. Three lectures, one recitation. Prerequisite, 4312 or equivalent and coregistration in Mathematics 421 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.

4514 Microwave Theory (g). Spring. Credit four hours. Three lectures, one recitation. Prerequisite, 4511 or equivalent. Mr. McIsaac.

Theory of passive microwave devices for propagating, storing, coupling, or radiating electromagnetic energy. Topics treated will include modes of homogeneous and inhomogeneous waveguides, perturbation theory for waveguides; scattering theory of multiport junctions, resonant cavities, directional couplers, isolators, circulators; propagation in gyrotropic media; periodic waveguides. At the level of *Field Theory of Guided Waves,* by Collin.

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; imoedance 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.

Laboratory

4421–4422 Advanced Electrical Laboratory (u,g). May be taken in the fall and spring terms consecutively or separately. Credit four hours. One lecture, two laboratories. Prerequisite, 4322 or consent of instructor.

Advanced experiments concerning a wide range of topics appropriate to electrical engineering; lectures concerning experimental techniques and practical aspects of electronics. About thirty different experiments are available concerning topics of transistor and tube amplifiers, feedback, class-C amplifiers and oscillators, gyrators, double-tuned circuits, push-pull amplifiers, multivibrators, operational amplifiers, switching systems, oscillator sychronization, noise properties, electrical machinery, microwave circuits, microwave propagation and scattering, semiconductor properties such as the hall effect and minority carrier mobility, helicon waves, Gunn and avalanche diode oscillators, lasers, propagation of electromagnetic waves, antennas, and plasmas. The student is expected to perform three or four experiments per term, selected to meet his needs. Emphasis is placed upon independent work.

Electronics

4431–4432 Electronic Circuit Design (u,g). Fall and spring. Credit three hours per term. Two lectures, one recitation, one laboratory. Prerequisite, 4322. Mr. Ingalls.

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. Prerequisites, 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 Other Curricula.)

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. Mr. Moog.

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.

4531 Quantum Electronics I (g). Fall. Credit four hours. Three lectures, one recitation-computing. Prerequisites, 4311, 4312 and Physics 443 or 4411. Mr. McFarlane.

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; characteristics of optical resonators. 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. Wolga.

A continuation of the treatment of the physical principles underlying optical masers and related fields. Topics will include: spectroscopy of free atoms, ions, molecules, semiconductors, and ions in crystals, with examples from important optical masers; survey of chemical and dye lasers; electrooptic interactions in solids; parametric and nonlinear processes; the principles of holography. At the level of *Quantum Electronics,* by Yariv, and *Fundamentals of Quantum Electronics,* by Pantell and Puthoff.

4534 Nonlinear and Quantum Optics (g). Spring. Credit four hours. Three lectures, one recitation. Prerequisite, 4531 or Physics 572. Mr. McFarlane.

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. Available to fourth-year students with permission of instructor. Mr. Dalman.

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. Available to fourth-year students with permission of instructor. Mr. Dalman.

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 three hours. Two lectures, one laboratory. Prerequisite, 4412 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. The proceedings of recent international solid state circuits conferences and relevant current publications are studied.

4631–4632 The Physics of Solid State Devices (g). Fall and spring. Credit two or three hours per term. Two lectures. Prerequisite, 4536 or permission of instructor. Mr. Lee.

The analysis of solid state devices of current interest (avalanche, LSA, Gunn devices, etc.) will be considered in sufficient detail to understand some of the limitations of analysis and/or physical understanding that are involved in the design of such devices. Toward this end, the relevant scattering methods which affect the transport properties of warm and hot charge carriers and the complications of band structure will be considered. In order to deal thoroughly with these basic aspects, the number of devices considered will be limited, but subjects of specific interest to individuals may 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 operation 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). Spring. Credit four hours. Three lecture-recitations, one computing. Prerequisites, 4322 or 4942 and consent of instructor. Not offered in 1970–71.

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 1970–71.

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.]

Radio and Plasma Physics

4461 Wave Phenomena in the Atmosphere (u,g). Fall. Credit three hours. Three lecture-recitations. Prerequisites, 4302, 4312. Mr. Bolgiano.

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. Prerequisites, 4312, 4401. Mr. Bolgiano.

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.

[4551–4552 Upper Atmosphere Physics I and II (u,g). Fall and spring. Credit three hours each term. Three lectures. Prerequisite, 4312 or equivalent. Not offered in 1970–71.

The physical processes governing the behavior of the earth's ionosphere and magnetosphere will be considered. 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. Prerequisites, 4311, 4312 or equivalent. Open to fourth-year students at discretion of instructor. Mr. Ott.

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. Not offered in 1970–71.

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. Prerequisites, 4312 and 4401 or equivalent.

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. Mr. Farley.

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.

4661 Kinetic Equations (g). Spring. Credit three hours. Three lectures. Prerequisite, Physics 561, 562 or permission of instructor. Mr. Liboff.

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.

Communications, Information, and Decision Theory

4472 Introduction to Algebraic Coding (u,g). Spring. Credit three hours. Three lectures. Prerequisite, Mathematics 293 or equivalent. Mr. Jelinek.

Design and analysis of codes for correction or detection of errors in digital data processing and transmission. Encoding and decoding algorithms and their implementation. Properties of linear sequential machines and feedback shift registers. The underlying algebraic theory (groups, finite fields, etc.) will be developed from the beginning as needed. The codes studied will include: group block codes, Hamming codes, Bose-Chaudhuri codes, cyclic codes, convolutional tree codes, and Reed-Muller codes. Majority logic (threshold) decoding and sequential decoding.

4501 Systems with Random Signals and Noise (g). Fall. Credit four hours. Three lectures, one recitation. Prerequisite, 4402 or consent of instructor. Mr. McGaughan.

Signal processing, linear, linear time invariant (LTI), and memory-less nonlinear transformations; causal and noncausal LTI systems; bounds on LTI signal processing systems; signal representation, orthogonal expansions, low-pass and band-pass signals and systems, analytic signals; probability, random variables, limit theorems, random vectors, and transformations of random vectors; introduction to random processes, stationary processes, correlation and power spectra; linear and memory-less nonlinear transformations of random processes; models for noise in physical systems, noise factor and noise temperature; selected topics in nonlinear processing of random signals.

4502 Statistical Aspects of Communication (g). Spring. Credit four hours. Three lectures, one recitation. Prerequisite, 4501 or consent of instructor. Mr. McGaughan.

Deterministic signals in additive noise, applications to radar detection, radar system parameters and design topics; system optimization, matched filters, matched filter realizations, signal design; linear smoothing and prediction of stationary processes, causal and noncausal filters, design topics for causal filters; modulation systems, performance of analog systems in time and frequency multiplex with additive noise; digital modulation systems; PCM systems with additive noise; optimum processing of digital data, signal design for digital transmissions, decision rules and 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. Prerequisites, 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 1970–71.

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 Transmission of Information (g). Fall. Credit four hours. Three lectures. Prerequisite, 4507 or Mathematics 571 or consent of instructor. Mr. Chang.

Application of information theory to the analysis and design of communication systems. Selection of fidelity criteria for accurate and efficient transmission of information. Efficient representation of outputs of message sources. The entropy measure and its properties. Encoding for reliable communication through discrete memoryless noisy channels. Rate of information transmission and the probability of decoding error, channel capacity. Systematic codes and the instrumentation problem. Sequential decoding. Coding and decoding for the band-limited Gaussian channel. Coding of sources with a fidelity criterion. At the level of *Probabilistic Information Theory,* by Jelinek.

4676 Decision and Estimation Theory for Signal Processing (g). Fall. 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. Mr. Kim.

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. Prerequisites, concurrent registration in 4401 or an equivalent background with consent of the instructor. Mr. Vrana.

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. Mr. Vrana.

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.

4487–4488 Switching Theory and Systems (u,g). Fall and spring. Credit three or four hours per term (four hours with laboratory). Three lectures, one laboratory. Prerequisite, Mathematics 293–294 or equivalent. First term prerequisite to second. Mr. Torng.

Mathematical foundation, switching devices, logical formulation and realization of combinational switching circuits; function minimization and decomposition, fault detection and diagnosis; implementation algorithms; threshold logic, number representation and codes; iterative network; simple memory devices; synchronous and asynchronous sequential circuit, regular expression; circuit equivalence; decomposition theorems and algorithms for secondary assignments; hazards in switching circuits; logic design of general-purpose digital computers. Topics for the optional laboratory session: design and construction with solid state modules of counters, shift registers, adders, other arithmetic circuits in digital computer, and general sequential networks.

4505 Approximation Techniques (g). Fall. Credit four hours. Three lectures. Prerequisite, 4402 or consent of instructor. Mr. Thorp.

Approximation techniques used in the synthesis of systems and signals, with applications in control and communication. Signal approximation problems; Kautz filters, measurement of expansion coefficients, complementary filters. Examples of signal approximation problems in biological and electrical systems. Optimal pole positions for exponential approximation. Computational methods for parameter optimization and approximation problems.

4506 Optimization Techniques (g). Spring. Credit four hours. Three lectures. Prerequisite, 4503 or consent of instructor. Mr. Merriam.

Optimization techniques used in the synthesis of systems, with applications in control. Formulation of deterministic control optimization problems; minimal time, minimal fuel, regulator problems. Introduction to variational methods. Solution of two-point boundary-value problems by control vector iteration. Synthesis of optimal feedback controllers.

[**4588 Bionics and Robots (Theoretical and Applied Mechanics 1857) (u,g).** Spring. Credit three hours. Prerequisites, elementary differential equations, linear algebra and probability, or consent of instructor. Mr. Block. Not offered in 1970–71.

Interactions between engineering and biology. The mechanization of biological functions such as learning, seeing, hearing, recognition, recall, instinctual behavior, theorem proving, game playing, navigating, exploring, cognition, homeostasis, optimization, adaptation to natural environments, heuristic reasoning, language acquisition and translation, self-organization, self-reproduction and self-repair, embryogensis, growth, evolution, and ecology. Cybernetics, information, reliable systems from unreliable components. Models: hardware, simulation, analysis. Neural nets, perceptrons, threshold logic, madelines, features in patterns. Artificial intelligence. Computers and the foundations of mathematics, Turing machines, computability, algebraic linguistics, Gödel's theorem, the Euler-Diderot metatheorem.]

[**4681 Random Processes in Control Systems (g).** Spring. Credit four hours. Three lectures. Prerequisites, 4508 and 4506. Not offered in 1970–71.

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.]

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.

4593 Fundamentals of Acoustics (u,g). Fall. Credit four hours. Three lectures, one laboratory. For graduate students and qualified seniors. Mr. Ingalls.

Vibrations in strings, bars, membranes, and plates; plane and spherical acoustic waves; transmission, reflection, absorption, resonators, filters; loudspeakers and microphones; speech, hearing, and noise; architectural acoustics; ultrasonic and sonar transducers; underwater acoustics. At the level of *Fundamentals of Acoustics,* by Kinsler and Frey.

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 in order 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 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. Prerequisites, Mathematics 192 and Physics 122.

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).

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.

4435 Electronics and Music (u,g). Fall. Credit three hours. Electrical engineering students may take the course as a free elective. Mr. Moog.

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.)

4940 Introductory Electrical Engineering (u). Fall and spring. Credit three hours. Two lectures, one recitation-computing. Prerequisites, Physics 122, and Mathematics 294 and Physics 223. Mr. Osborne.

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 course descriptions for *Applied Physics*, p. 89.

Environmental Systems Engineering

See p. 96.

Geotechnical Engineering

See p. 99.

Industrial Engineering and Operations Research

Service Courses

9114 Consumer Products Engineering (Same as Chem. Eng. 5790) (g). Fall. Credit three hours. Two lectures, one computing. Open to qualified seniors and M.Eng. students. Mr. Hedrick.

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.

9160 Introductory Engineering Probability (u). Spring only in 1970–71; thereafter, both terms. Credit three hours. Two lectures, one recitation. Prerequisite, first year calculus. Mr. 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 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, and other distributions, and how they arise in practice; and Markov chains and applications.

9170 Basic Engineering Statistics (u). Fall only in 1970–71; thereafter, 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, the best next step is a course in probability (for example 9360). 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 of 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

9301 Man-Machine Systems and the Industrial Engineer (u). Fall. Credit three hours. Two lectures, one recitation. Messrs. Goode and Saunders.

Describes the historical development, as well as the modern activities, of the industrial engineer/operations researcher. Emphasis will be on manufacturing and distribution systems, but other topics will include information systems, hospital systems, handling and transportation systems, etc. Problems will be discussed and relevant techniques available to the engineer for analysis and synthesis will be identified and briefly described.

9310 Industrial Engineering Analysis (u). Fall. Credit four hours. Three lectures, one computing. Prerequisites, 9350 and 9370 or equivalent. Mr. Goode.

Selected methods of industrial engineering 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 Engineering Design (u). Spring. Credit four hours. Three lectures, one computing. 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). Spring. Credit four hours. Three lecture-recitations, one computing. 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: that is, 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, understanding of the properties (and limitations) of specific models, and familiarity with computational methods, such as the Simplex method, and why they work.

9321 Probabilistic Models in Industrial Engineering and Operations Research (u,g). Spring. Credit four hours. Three recitations, one computing. Prerequisite, 9360 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.

9350 Cost Accounting, Analysis, and Control (u). Spring. Credit four hours. Three lecture-recitations, one computing. 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.

9360 Introduction to Probability Theory with Engineering Applications (u). Fall. Credit four hours. Three lecture-recitations, one computing. Prerequisite, Mathematics 294 or equivalent. Mr. Stidham.

Definition of probability and basic rules of probability theory. Random variables, probability distributions, and expected values. Special distributions important in engineering work and relations among them; elementary limit theorems. Introduction to stochastic processes and Markov chains and their applications in the construction of mathematical models of operation, with emphasis on queuing and inventory models.

9370 Introduction to Statistical Theory with Engineering Applications (u). Spring. Credit four hours. Three lectures, one recitation. Prerequisite, a course in probability (for example 9160). Staff.

Aims to provide 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. To this end, 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, 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. Prerequisites, Computer Science 202 or Operations Research 9381. Mr. Morgan.

Applying 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 Honors Section 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 lecture-recitations, one computing. Mr. Brown.

Covers the same topics as 9360, but all lectures and computings are independent of those for 9360.

9470 Introduction to Statistical Theory with Engineering Applications (u,g). Spring. Credit four hours. Three lectures, one recitation-computing. Prerequisite, 9360 or 9460. Staff.

Covers the same topics as 9370 described above, but all lectures and computings are independent of those for 9370.

Elective and Graduate Courses

[9511 Industrial Systems Design (u,g). Spring. Credit four hours. Two lectures, one recitation. Not offered in 1970–71. Intended for advanced undergraduates and graduates seeking degrees in engineering.

A discussion of the problems of design and control of industrial systems. The development of design alternatives and their evaluation. Measures of system effectiveness and sensitivity. The role and place of information handling in systems control. Experimental procedures in testing system design with computer simulation. Term papers and design projects by individuals and groups will be expected.]

[9512 Statistical Methods in Quality and Reliability Control (g). Spring. Credit three hours. Three lectures. Prerequisite, 9370 or equivalent. Not offered in 1970–71.

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. Prerequisites, 9320 and 9370 or permission of instructor. Not offered in 1970–71.

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 lecture-recitations, one computing. Prerequisites, 9320 and 9321, or permission 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. Three lecture-recitations. Prerequisite, permission of the 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 programming, 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, 9360, 9170, or permission of the instructor. Not open to students who have had 9526. Mr. Stidham.

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.

[9524 Problems in Operations Research (g). Credit three hours. One two-hour meeting weekly. Prerequisite, 9523 or equivalent. Not offered in 1970–71.

An advanced seminar concentrating on problem definition, measures of effectiveness, applicability of various analytical methods to the solution of real problems.]

[9525 Flow and Scheduling in Networks (g). Spring. Credit three hours. Three lecture-recitations. Not offered in 1970–71.

Network analysis for continuous static flow; feasibility theorems, capacity determination, minimal cost operation. Sequencing models for deterministic discrete flow networks. Determination of capacity, routing, and discipline for networks of queues.]

9526 Mathematical Models—Development and Application (g). Fall. Credit four hours. Three lecture-recitations, one computing. Prerequisites, 9320 and 9321, 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. Prerequisites, 9360 or permission of the instructor. Mrs. Dafermos and Mr. Stidham.

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 lectures. Prerequisites, 9360 and 9320. Mr. Nemhauser.

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 I (g). Spring. Credit three hours. Three lectures. Prerequisites, Mathematics 331, Mathematics 411 or 9320, or permission of the instructor. Mr. Eisner.

The geometry and duality of linear programming. Complete regularization and the resolution of degeneracy. Adjacent extreme point methods such as simplex, dual, and multipage in linear and nonlinear problems. Models of transportation and network type, and zero-sum and two-person games. Mixing routines and decomposition. Introduction to integer programming. Convex programming and Kuhn-Tucker theory.

9531 Mathematical Programming II (g). Fall. Credit three hours. Three lecture-recitations. Prerequisite, 9530. Mr. Nemhauser.

Complementary pivot theory. Semiinfinite programming and duality in convex programming. Computational algorithms. Integer programming. Chance-constrained programming and piecewise linear decision rules. Combinatorial analysis and external methods.

9533 Combinatorial Analysis (g). Fall. Credit three hours. Three lecture-recitations. Mr. Billera.

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. Not offered in 1970–71.

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 Game Theory (g). Fall. Credit three hours. Three lecture-recitations. Prerequisite, permission of the instructor. Mr. Lucas.

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 infinitely many players. Economic market games.

9537 Dynamic Programming (g). Fall. Credit three hours. Three lecture-recitations. Prerequisite, 9560. Mr. Nemhauser.

Dynamic programming as a computational technique for solving a wide variety of problems. Concentration on deterministic problems: the knapsack problem, the obstacle course problem, finite horizon inventory models with known demand. Introduction to Markov sequential decision problems; Howard's algorithm in the finite state and action space case.

9539 Selected Topics in Mathematical Programming (g). Spring. Credit three hours. Three lecture-recitations. Prerequisite, 9532. Mr. Eisner.

Topics chosen from current research areas such as integer programming over finitely generated groups, chance-constrained games, duality theory, infinite games.

9550 Engineering Economic Analysis (g). Fall. Credit three hours. Three lectures. Mr. Morgan.

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 1970–71.

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 intensive discussion of transfer pricing.]

9560 Applied Stochastic Processes (g). Spring. Credit four hours. Three lectures, one recitation. Open to qualified undergraduates. Prerequisites, a good first course in probability (for example, 9460 or Mathematics 371), or a similar degree of sophistication (9160 plus 9321, for instance). Mr. Taylor.

An introduction to stochastic processes emphasizing 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. Two recitations, one computing. Prerequisites, 9360 and permission of the instructor. Staff.

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. Prerequisites, 9321, and permission of the instructor. Mr. Emmons.

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 analyses of inventory problems; renewal theory applied to inventory problems; multiechelon problems; statistical problems; and production smoothing.

9565 Time-Series Analysis (g). Spring. Credit three hours. Three lectures. Prerequisite, permission of the instructor. Mr. Brown.

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). Either term. Credit three hours. Three lectures. Prerequisites, 9560 and permission of the instructor. Mr. Taylor.

Selected topics in applied probability for advanced students. Topics will be chosen from current literature and research areas of the staff.

[**9570 Intermediate Engineering Statistics (g).** Fall. Credit three hours. Two recitations, one computing. Prerequisite, 9370, 9470, or permission of the instructor. Not offered in 1970–71.

Distributions used in the analysis of the properties of standard statistical tests, including noncentral chi-square and 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). Fall. Credit four hours. Two recitations, one computing. 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 recitations. Prerequisite, 9370, 9570, or equivalent. Mr. Weiss.

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). Spring. Credit three hours. Two recitations, one computing. 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. Not offered in 1970–71.

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. Two recitations, one computing. Prerequisite, 9570 or permission of the instructor. Not offered in 1970–71.

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. (Ind.) students. Prerequisites, 9381 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. Prerequisite, 9381 or permission of the instructor. Mr. Conway.

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. Prerequisites, Computer Science 401 and permission of the instructor. Not offered in 1970–71.

Selected topics in the design of computer systems to implement operations research techniques. To be discussed in fall 1971: mathematical programming and inventory control systems.]

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.

Study, under direction, of special problems in the Field of Industrial Engineering and Operations Research. (Register only with the registration officer of the school.)

9591 Operations Research Graduate Seminar (g). Fall and spring. Credit one hour. Messrs. Eisner and Brown.

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. Mr. 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 a 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 industrial engineering problem. The solutions must be defended on sound engineering and economic arguments. Final bound copies of each project report must be filed with the School.

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. Prerequisite, 6211.

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 the 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 (Mechanical) (u). Fall. Credit three hours. Three lectures.

Relation of basic and applied sciences to the processing of materials. The effect of processing on the properties of the materials and control of material properties by variations in processing are emphasized. Processing methods considered include solidification, deformation, heat treatment, material bonding, material removal, consolidation of powders, and others.

6046 Materials Processing II (Chemical) (u). Spring. Credit three hours. Three lectures.

Principles of materials processing (chemical) are discussed, including application of thermodynamics and kinetics principles; momentum, heat and mass transfer, and process control.

6210–6211 Materials Science (u). Either term. Credit three hours. Two lectures, one laboratory or recitation.

An introduction to the basic concepts of materials science. Structure: structure of gases, liquids, and solids; atomic binding; observations of structure by x-ray diffraction; packing concepts and crystalline defects; microstructures. Kinetics: reaction rates in gases and condensed systems; atomic and ionic transport processes; kinetics of phase transformation. Properties: mechanical, electrical, and magnetic properties of materials with emphasis on structure-sensitive properties.

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 nonchemical 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 Livington 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 viscoelastic 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). Credit three hours. Offered jointly with Applied Physics 8211.

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). Spring. Credit three hours. Three lectures. Prerequisite, 6611 or consent of instructor. Offered jointly with Applied Physics 8212.

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). Spring. Credit three hours. Guest lecturers. Joint staffing: Materials Science and Engineering and Theoretical and Applied Mechanics.

Same as Theoretical and Applied Mechanics 1280. The physical basis of the strength, elastic modulus, and fracture resistance of composite materials; the micro- and macromechanics 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). Spring. Credit three hours. Three lectures. Offered jointly with Applied Physics 8262.

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 productions, 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,* and *Thermal Engineering.*

General

3053 Mechanical Engineering Laboratory (u). Fall. Credit four hours. One lecture, two laboratories. Prerequisites, 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. Prerequisites, 3326, 3324, 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. (Mech.) 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 most cases, the project is performed in collaboration with an industrial company or institution, 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). Credit three hours for two semesters' work; one class meeting per week first semester; two class meetings per week second semester. Taught in alternate years. 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.

3324 Vibration and Control of Mechanical Systems (u). Fall. Credit three hours. Two recitations, one laboratory. Prerequisite, 3321 or 3331. (Will not be offered after fall 1970.)

Free, damped, and forced vibrations. Vibration isolation mounts, absorbers, and dampers. Control systems: the Laplace transform, transient response to specific inputs, transfer functions, frequency response, stability. Analog computer solutions. Laboratory on the vibration of machines and their components and on hydraulic and electromechanical control circuits. Modern instruments for measuring force and motion.

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 or 3331.

Consideration of the dynamic behavior of systems with emphasis on modeling and analysis techniques and their application. Discipline-oriented topics would 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.

3331 Kinematics and Components of Machines (u). Spring. Credit three hours. Two lecture-recitations, one computing. Prerequisite, 212 or equivalent.

May be elected by qualified students not in mechanical engineering. Theory and analysis of mechanisms and components based on consideration of motion, velocity, acceleration, material, strength, and durability. Cams, linkages, couplings, clutches, brakes, belts, chains, gears, bearings, shafts, and springs.

3361 Advanced Mechanical Analysis (g). Fall. Credit three hours. Three recitations. Prerequisite, 3322 or 3331. 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. Two recitations, one design or laboratory period. Prerequisites, 3322 or 3331 and 3431 or equivalent, or permission of the instructor. Mr. DuBois.

Principles and methods of design to improve the producibility of machines and products. Design techniques to simplify and improve the processing operations, to reduce cost, and to increase accuracy and reliability. Designs and operation sequences for small-lot and large-lot manufacture to exploit the capabilities inherent in machine tools, jigs and fixtures, and other production equipment. Applications of the foregoing by design exercises.

[**3366 Advanced Kinematics (u,g).** Fall. Credit three hours. Two recitations, one computing. Prerequisite, 3321 or 3331. Not offered 1970–71.

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, 3324 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, 3322 or 3331.

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 are studied as applied to machine design problems.

3374 Conceptual Design (g). Fall. Credit three hours. Three recitations. Prerequisite, 3322 or equivalent. Open to qualified undergraduates by permission of instructor. Mr. DuBois.

Conception and initial design of products and machines; improving machine appearance. Methods to stimulate mechanical ingenuity. Principles of synthesis and creativity employing association, inversion, and other techniques. Sketching, class discussion, and comparative evaluation of solutions.

3375 Automatic Machinery (u). Spring. Credit three hours. Two recitations, one field trip. Prerequisite, 3321 or 3331. 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). Spring. Credit three hours. Three recitations. Prerequisite, 3322. Mr. DuBois.

Analysis of various designs for the parts of an automotive vehicle, other than the engine, in relation to its performance; stability, weight distribution, traction, steering, driving, braking, riding comfort, power required and available, transmission types, acceleration, and climbing ability. Recommended together with course 3670 for a study of automotive engineering.

3378 Automatic Control Systems (g). Spring. Credit three hours. Two recitations, one laboratory. Open to qualified undergraduates. Prerequisite, 3324 or equivalent. Mr. Krauter.

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. Also, 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 will be required containing recommendations and reasoning leading to these considerations.

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, 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 of design problems frequently encountered in mechanical systems as optimization problems, with emphasis 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 to be drawn from structures and machine components frequently encountered in mechanical systems.

3387 Dynamics of Vehicles (u,g). Credit two hours. Prerequisites, 1021 and 1031 (or equivalents) and permission of instructor. Mr. Krauter.

Selected topics in vehicle dynamics, with emphasis on the articulated vehicle. Development of nonlinear equations for a tractor-semitrailer. Discussion of tire behavior, safety devices, and the fifth wheel. Application to jackknifing. Linear representation and stability. Also, automobile handling, suspension, and safety.

3388 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 announced prior to beginning of term. More than one topic may be taken if offered.

Materials Processing

3431 Materials Processing (u). Fall and spring. Credit three hours. One lecture, two laboratories. Mr. Geer.

Comprehensive studies of materials and machinery involved in material removal. Force, deformation, and power relationships. Single-tooth, multiple-tooth, and multitooth tool capabilities. Ultrasonic, electrical discharge, electrochemical, and other "nonchip" removal processes. Process planning. Thread and gear manufacturing. Metrology, fixed and comparative systems of gaging. Surface texture determination. Quality control systems.

3451 Material Removal Systems (u,g). Fall. Credit three hours. One lecture, two laboratories. Prerequisites, 3431, 6316. Mr. Geer.

Advanced study of mechanics of chip formation. Forces and power dynamometry. Orthogonal and three-dimensional relationships. Cutter geometry and chip control. Nonchip techniques using chemical, electrical, ultrasonic, and other media; surface characteristics; and postprocess treatments.

3461 Quality Assurance Systems (u). Either term. Credit three hours. Two lectures, one laboratory. Prerequistes, 3431, 9170. Mr. Geer.

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.

Thermal Engineering

3621 Thermodynamics (u). Fall and spring. Credit three hours. Three recitations. Prerequisites, Mathematics 191 and 192, Physics 121 and 122.

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). Spring. Credit four hours. Four recitations. Prerequisites, Mechanics 212, 3621.

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. Prerequisites, 3621, 3623.

Conduction of heat in the 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.

3641 Power Systems (u). Spring. Credit three hours. Prerequisites, 3621 and 3623 or equivalent.

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 Problems (u). Fall. Credit three hours. Prerequisites, 3623, 3631.

Introduction to the problems resulting from the interaction of technology and environment and to possible technical solutions to these problems. Specifically, the problems of automobile-induced air pollution and thermal pollution will be discussed. These discussions will include considerations of combustion generated pollution, photochemical smog, atmospheric dispersion of pollutants, alternate motive power sources, natural heat balance for rivers and lakes, effect of thermal pollution, fluid-mechanical aspects of heat dispersion, and alternative methods of heat rejection.

3652 Combustion Theory (u,g). Spring. Credit three hours. Three lectures. Prerequisites, 3625 or equivalent and some familiarity with statistical and classical thermodynamics. Mr. Torrance.

Application of fluid mechanics, thermodynamics, and heat and mass transfer to combustion processes. Topics include chemical kinetics and transport properties; dissociation and heat of combustion; flames in homogeneous mixtures and diffusion flames; ignition, quenching, and burning limits; flame propagation and stabilization; deflagrations, detonations, and explosions; burning of droplets and particles. At a level between *Fundamentals of Combustion,* by Strehlow and *Combustion Theory,* by Williams.

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 students, whether graduate or undergraduate. 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 and 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. Prerequisites, 3621, 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. Prerequisites, basic thermodynamics and fluid mechanics. Mr. Gebhart.

Description of modes of thermal and mass diffusion and transport. Mechanics of molecular diffusion in gases. Formulation of the transport equations and their application in engineering and in the environment. Conduction and mass diffusion in solids. Thermal radiation between surfaces and as a diffusion process in non-opaque media. Energy and mass diffusion by molecular and turbulent processes in convection. Consideration of forced and natural convection transport in fluids. Various aspects of buoyancy-induced flows will be emphasized.

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. Prerequisites, 3621, 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 (g). Spring. Credit three hours. Three lectures. Open to qualified undergraduates. Prerequisite, 3621 or equivalent. Mr. Conta.

Primarily an analysis of energy conversion devices from a classification 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 arranged. Prerequisite, 3623, Physics 443, or consent of instructor. Mr. Cool.

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). Fall. Credit three hours. Three lectures. Prerequisites, 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). Fall. Credit two hours. Two lectures. Prerequisites, 7301 or 3665 or familiarity with the partial differential equations of fluid mechanics; Computer Science 311 or some familiarity with basic Fortran programming. Mr. Torrance.

Finite-difference methods for solving problems in fluid flow and heat transfer are developed. Steady and unsteady states; two and three space dimensions. Physical and numerical restraints imposed on the numerical solutions are considered. Recent methods are discussed and compared. Application to problems in natural convection, flow over solid bodies and within channels, meteorology. Final examination requires solution of a fluid flow problem on a digital computer. At the level of *Difference Methods for Initial-Value Problems,* by Richtmyer and Morton, but with greater physical emphasis.

3680 Convection Heat Transfer (g). Spring. Credit three hours. Three recitations. Prerequisite, 3665 or consent of instructor. Mr. Gebhart.

Processes of the diffusion of thermal energy, mass, and momentum are considered. Basic equations are reasoned in detail and applied to the kinds of problems important in engineering and in environmental and ecological studies. Natural convection (buoyancy-induced) flows are considered in detail. Convection layers adjacent to surfaces, plumes, buoyant jets, and thermals in extensive media (including stratified) are treated for laminar and turbulent processes. Transients are analyzed. Laminar flow transition to turbulence is analyzed. Thermal instability and resulting flows are considered. Diffusion characteristics in naturally occurring bodies of fluid are studied. Forced convection is considered, including effects of appreciable variation of properties and viscous dissipation. The nature of convection flows combining buoyancy and velocity-induced transport, such as those in the atmosphere and adjacent to heated surfaces, is discussed. 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 the results from analysis and observation.

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.

3690 Special Investigations in Thermal Engineering (u). Fall and spring. Credit by arrangement.

Intended either for informal instruction to 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. 130.

Nuclear Science and Engineering

See course descriptions for *Applied Physics*, p. 89.

Operations Research

See course descriptions for *Industrial Engineering and Operations Research*, p. 121.

Structural Engineering

See p. 102.

Theoretical and Applied Mechanics

For Undergraduates Only

293–293H Engineering Mathematics (u). Either term. Credit four hours. Prerequisite, 192 or 194. Fall term: lectures, M W F 8, 12:20, plus recitation periods to be arranged. Spring term: M W F S, 9:05, 11:15. 293H is an Honors section in the fall term only. (Preliminary examinations: Oct. 13, Nov. 10, and Dec. 8 at 7:30 p.m.)

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. Fall term: M W F 8, 12:20. Spring term: lectures, M W 8, 12:20, plus recitation periods to be arranged. 294H is an Honors section in the spring term only. (Preliminary examinations: Mar. 2, Mar. 23, and May 5 at 7:30 p.m.)

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 *Engineering Science Mechanics,* by Long.

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, registraton 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 *Engineering Mechanics,* by Shames.

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. 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 interative 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. Mr. Lance.

Includes mathematical methods in applied science with emphasis on applications of importance in engineering. Mathematical topics include ordinary differential equations, Fourier series, and partial differential equations. Applications to heat flow, reaction rates, diffusion, wave propagation, dynamic response. Slightly below the level of *Mathematics of Physics and Modern Engineering,* by Sokolnikoff and Redheffer.

1151 Advanced Engineering Analysis II (u,g). Spring. Credit three hours. Prerequisite, 1150 or equivalent. Mr. Lance.

A continuation of 1150, including partial differential equations and boundary-value problems, vector fields, complex variables, Laplace transformations. Applications to heat flow and diffusion, fluid flow, electrodynamics. Slightly below the level of *Mathematics of Physics and Modern Engineering,* by Sokolnikoff and Redheffer.

1180 Methods of Applied Mathematics I (g). Fall. Credit three hours. Three lectures. Graduate students or undergraduate students with the consent of the instructor.

Emphasizes applications and techniques of solution, wherever possible. It is intended for students who plan to use applied mathematics frequently; many students will supplement it with 1182(–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. 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. Three lectures. Prerequisite, 1181 or equivalent. Mr. Ludford.

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.

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

1263 Applied Elasticity (u,g). Fall. Credit three hours. Three lectures. 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.

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. Three lectures. Not offered in 1970–71.

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. Mr. Robinson.

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. Shakedown. Selected topics in dynamic plasticity.

1269 Thermal Stresses (u,g). Fall. Credit two hours. Mr. Boley.

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. Mr. Boley.

A study of the various energy methods used in structural analysis. Principle of virtual work. Strain energy and complementary energy theorems. Reciprocal theorems. Elastic and inelastic analyses. Dynamical problems. Energy stability criteria.

1280 Composite Materials (u,g). Spring. Credit three hours. Same as Materials Science and Engineering 6625. Staff in the Departments of Theoretical and Applied Mechanics and Materials Science and Engineering.

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. Dafermos. Not offered in 1970–71.

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. Not offered in 1970–71.

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 1970–71.

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. Three lectures, one laboratory. Mr. Pao.

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. Not offered in 1970–71.

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. Three lectures. For graduate students or advanced undergraduate students with consent of instructor. Mr. Alfriend.

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. At the level of *Introduction to Advanced Dynamics,* by McCuskey.

1371 Advanced Dynamics (g). Spring. Credit three hours. Three lectures. Mr. Alfriend.

Lagrangian mechanics, principle of least action, Hamilton's principle; Hamilton's canonical equations of motion, Hamilton-Jacobi theory, perturbation theory, quantum mechanics, special relativity. At the level of *Classical Mechanics,* by Goldstein.

1375 Nonlinear Vibrations (g). Spring. Credit three hours. Three lectures. Prerequisite, 1362 or equivalent. Mr. Rand.

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.

Experimental Mechanics

1459 Experimental Mechanics (u,g). Fall. Credit three hours. Mr. Robinson.

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.

Space Mechanics and Aerospace Structures

[1730 Aerospace Structures I (u,g) (Civil Engineering 2730). Fall. Credit three hours.

Three lectures. Prerequisites, Mechanics 211 and 212. Not offered in 1970–71.

Evolution of aerospace structural design concepts and the structural design cycle. Environment, structural-design inertia, and specifications for aircraft, missiles, and spacecraft. Inertia loads, load factors, flight envelopes, gust loads. Aerodynamic and solar heating; loads in space flight. Materials of construction and their properties; elastic and inelastic behavior, fatigue. Theories of failure. Fracture mechanics. Elementary structural analysis.]

[1731 Aerospace Structures II (u,g) (Civil Engineering 2731). Spring. Credit three hours. Three lectures. Prerequisites, Mechanics 211 and 212. Not offered in 1970–71.

Structural problems and configurations of aircraft, missiles, and spacecraft. Analysis and design of thin-walled members in bending, torsion, and combined loadings. Reinforced stressed-skin construction, thick-shell construction, sandwich and composite materials. Inelastic analyses: plastic and viscoelastic behavior. Buckling, torsional instability, and crippling of thin-walled beams; creep buckling. Buckling and post-buckling behavior of plates; effective width. Thermal stresses and high-temperature effects.]

1772 Space Flight Mechanics (u,g). Fall. Credit three hours. Three lectures. 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. Mr. Burns.

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 1970–71.

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.]

Bionics and Robots

[1857 Bionics and Robots (u,g) (Electrical Engineering 4588). Spring. Credit three hours. Prerequisites, elementary differential equations, linear algebra and probability, or consent of instructor. Open to undergraduates or graduates. Mr. Block. Not offered in 1970–71.

Interactions between engineering and biology. The mechanization of biological functions such as learning, seeing, hearing, recognition, recall, instinctual behavior, guessing, theorem-proving, game-playing, navigating, exploring, cognition, homeostasis, optimization, adaptation, heuristic reasoning, communication, language acquisition and translation, self-organization, self-reproduction and self-repair, embryogenesis, growth, evolution, and ecology. Cybernetics, information, reliable systems from unreliable components. Models: hardware, simulation, analysis. Neural nets, perceptrons, threshold logic, madelines, features in patterns. Artificial intelligence. Computers and the foundations of mathematics, Gödel's theorem, Turing machines, computability. Finite-state machines and algebraic linguistics.]

Special Courses

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. 133.

Water Resources Engineering

See p. 104.

Courses of Interest to Students from Other Schools and Colleges in the University

201 (Civil Engineering) Microeconomic Analysis (u). Fall. Credit three hours. M W F 10:10. Prerequisite, one year of college level mathematics. Mr. Falkson.

Topics include the theory of the firm, production, market structures, consumer behavior, and welfare economics. May not be taken for credit in addition to Econ. 102.

201 (Computer Science) Survey of Computer Science (u). Fall. Credit three hours. M W F 9:05. Mr. Conway.

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 (Civil Engineering) Macroeconomic Analysis (u). Spring. Credit three hours. M W F 10:10. Prerequisite, 201. Mr. Falkson.

Topics include the theory of international trade, national income determination, economic growth and stability, and monetary and fiscal policy. May not be taken for credit in addition to Econ. 101.

202 (Computer Science) Computers and Programming (u). Either term. Credit three hours. Prerequisite, 201 or some programming experience in an algebraic language. M W F 9:05. Messrs. Morgan and Horowitz.

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.

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 7:30–9:30 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. Possible topics for exploration are: energy needs and the effects of energy generation on the environment; the capabilities and social impact of the computer; problems and opportunities in medical care and public health; transportation systems and their economic, social, and environmental impact.

301 (Civil Engineering) Microeconomic Analysis (g). Fall. Credit three hours. Mr. Falkson.

An introduction to microeconomic analysis for graduate students. The same lectures are offered as in 201, but there is a more intensive reading list.

302 (Civil Engineering) Macroeconomic Analysis (g). Spring. Credit three hours. Mr. Falkson.

An introduction to macroeconomic analysis for graduate students. The same lectures are offered as in 202, but there is a more intensive reading list.

[1857 (Theoretical and Applied Mechanics) Bionics and Robots (u,g). Spring. Credit three hours. Prerequisites, elementary differential equations, linear algebra, and probability, or consent of the instructor. Mr. Block. Not offered in 1970–71.

Interactions between engineering and biology. The mechanization of biological functions such as learning, seeing, hearing, recognition, recall, instinctual behavior, guessing, theorem-proving, game-playing, navigating, exploring, cognition, homeostasis, optimization, adaptation, heuristic reasoning, communication, language acquisition and translation, self-organization, self-reproduction and self-repair, embryogenesis, growth, evolution, and ecology. Cybernetics, information, reliable systems from unreliable components. Models: hardware, simulation, analysis. Neural nets, perceptrons, threshold logic, madelines, features in patterns. Artificial intelligence. Computers and the foundations of mathematics, Gödel's theorem, Turing machines, computability. Finite-state machines and algebraic linguistics.]

4110 (Electrical Engineering) Computer Appreciation (u). Either term. Credit three hours. Two lectures, one laboratory. No technical background beyond high school mathematics is required.

A course that deals with the 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). 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. Mr. Moog.

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. Mr. Watt.

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.

University Administration

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Robert A. Plane, University Provost
Mark Barlow, Jr., Vice President for Student Affairs
Lisle C. Carter, Jr., Vice Provost for Social and Environmental Studies
W. Donald Cooke, Vice Provost for Research
Lewis H. Durland, University Treasurer
W. Keith Kennedy, Vice Provost
Samuel A. Lawrence, Vice President for Administration
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Faculty and Staff of the College of Engineering

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Jeanette Wood, B.S., Librarian, College of Engineering Library

Emeritus Professors

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Lawrence Adams Burckmyer, 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
Roy Edwards Clark, M.E., Professor of Heat-Power Engineering, Emeritus
John C. Gebhard, C.E., P.E., Professor of Civil 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
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
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

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