Cornell University

ANNOUNCEMENTS

College of *Engineering*

1968-69

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 prepared especially for precollege students, should also be obtained, for it describes the many career opportunities in engineering today, and additionally the Cornell campus environment. Both of these Announcements 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 assistance, and degree requirements. It may be obtained by writing Cornell University Announcements, Day Hall, Ithaca, New York 14850.

Cornell University

College of Engineering

1968-69

Cornell Academic Calendar

	1968-69*
Orientation, new students:	
Convocation, 2:00 P.M.	Th, Sept. 12
Registration, new students	F, Sept. 13
Registration, old students	S, Sept. 14
Fall term instruction begins, 7:30 A.M.	M, Sept. 16
Midterm grade reports due	S, Oct. 26
Thanksgiving recess:	
Instruction suspended, 1:10 P.M.	W, Nov. 27
Instruction resumed, 7:30 A.M.	M, Dec. 2
Fall term instruction ends, 1:10 P.M.	S, Dec. 21
Christmas recess:	
Independent study period begins	M, Jan. 6
Final examinations begin	M, Jan. 13
Final examinations end	T, Jan. 21
Intersession begins	W, Jan. 22
Registration, old students	F, Jan. 31
Registration, new students	S, Feb. 1
Spring term instruction begins, 7:30 A.M.	M, Feb. 3
Deadline: changed or make-up grades	M, Feb. 10
Midterm grade reports due	S, Mar. 15
Spring recess:	
Instruction suspended, 1:10 P.M.	S, Mar. 29
Instruction resumed, 7:30 A.M.	M, Apr. 7
Spring term instruction ends, 1:10 P.M.	S, May 17
Independent study period begins	M, May 19
Final examinations begin	M, May 26
Final examinations end	T, June 3
Commencement Day	M, June 9
Deadline: changed or make-up grades	M, June 16

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

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

CORNELL UNIVERSITY ANNOUNCEMENTS

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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 which matches his curriculum with the continually changing needs of the engineering profession. 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 as it did subjects like engineering and agriculture as well as the traditional 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, Arts and Sciences, Home Economics, 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 are also 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, and Cornell engineering students are diverse. Each is encouraged in his individual educational interests, and this enables the College to provide 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 here.

Today approximately 2,000 undergraduate engineers are enrolled in the various schools and departments of the College of Engineering. In addition, about 700 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 professional study. 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 page 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 Machine Design and Materials Processing 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 the Field of Agricultural Engineering, all freshmen and sophomore engineering students are enrolled in the Division of Basic Studies (see page 26) 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 page 34).
Chemical Engineering (see page 41).
Civil Engineering (see page 47).
Electrical Engineering (see page 57).
Engineering Physics (see page 63).
Industrial Engineering and Operations Research (see page 70).
Materials Science and Engineering (see page 75).
Mechanical Engineering (see page 81).
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 page 53).

Graduate Curricula

The College of Engineering offers two distinct Masters' degree programs. One leads to a professional Master's degree, for example, Master of Engineering (Mechanical), 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

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

of Philosophy degrees are under the jurisdiction of the University's Graduate School. The professional Masters' degrees are administered by the Engineering Division of the Graduate School unless noted otherwise.

MASTER OF ENGINEERING DEGREES

Aerospace Engineering: administered by the Graduate School of Aerospace Engineering (see page 32).
Agricultural Engineering (see page 38).
Chemical Engineering (see page 44).
Civil Engineering (see page 50).
Electrical Engineering (see page 62).
Engineering Physics (see page 68).
Industrial Engineering and Operations Research (see page 74).
Materials Science and Engineering (see page 80).
Mechanical Engineering (see page 86).
Nuclear Engineering (see page 89).

MASTER OF SCIENCE AND DOCTOR OF PHILOSOPHY DEGREES

For those general degrees, administered by the Graduate School of the University, the faculty is organized into "Fields of Instruction." Most of these Fields coincide with the respective engineering schools or departments. However, in some instances, the faculty is drawn from more than one college at Cornell, and are so indicated in the Fields listed below.

For each Field there is given below an approved list of titles from which candidates for advanced general degrees choose major and minor subjects. 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 (with Agriculture)
Agricultural Engineering, Agricultural Structures. Electric Power and Processing, Power and Machinery, Soil and Water Engineering.

APPLIED PHYSICS (with Arts and Sciences)
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 (with Arts and Sciences)
Computer Science, Information Processing, Numerical Analysis, Theory of Computation.

ELECTRICAL ENGINEERING
Electrical Engineering, Electrical Systems, Electrophysics.

OPERATIONS RESEARCH
Applied Statistics and Probability, Engineering Administration, Industrial Engineering, Information Processing, Operations Research, Systems Analysis and Design.

MATERIALS SCIENCE AND ENGINEERING
Materials and Metallurgical Engineering, Materials Science.

MECHANICAL ENGINEERING
Machine Design, Materials Processing, Thermal Power, Thermal Processes.

NUCLEAR SCIENCE AND ENGINEERING (with Arts and Sciences)
Nuclear Engineering, Nuclear Science.

THEORETICAL AND APPLIED MECHANICS
Fluid Mechanics, Mechanics of Materials, Solid Mechanics.

WATER RESOURCES (with Agriculture, Arts and Sciences)
Water Resources.

THE ENGINEERING CAMPUS

Buildings and Laboratories

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 *Nuclear Reactor Laboratory* housing both a TRIGA and a "zero power" reactor, a gamma irradiation cell and a low energy ion accelerator, is also located on the Engineering Quadrangle.

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. 26–96.)

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.

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 its Department of Machine Design and Materials Processing and Department of Thermal Engineering. Also housed in Upson Hall is 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.

Library Resources

The engineering library, in Carpenter Hall, houses a collection of some 90,000 books and periodicals. Among the specialized holdings of the Engineering Library are a full depository collection of the U.S. 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 U.S. 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 new physical sciences library in Clark Hall and in the mathematics library.

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 reaches 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 years completing the requirements for his undergraduate degree. He then will go on to graduate study or will seek employment.

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 which 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.

Cornell's programs reflect the nationwide trend toward graduate and advanced study in engineering. They provide flexibility for responding to the enormous and changing demands on engineering education and engineering practice. At the same time Cornell retains one of the features for which it has long been recognized—strong programs leading to practice in the major fields of professional 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 pages 41–88, and the *College Program* is described on page 53).

All freshmen undertake a common program of studies, except for those who obtain advanced placement. Mathematics, physics, chemistry, and a liberal studies elective are included in the freshman year. In addition, one introductory engineering course taught by members of the engineering faculty is offered each term. One of these introduces fundamentals of engineering graphics and the role that the design function plays in modern engineering. The other course stresses the functions of modern engineering, the nature of engineering and the interrelationships of several professional fields. Freshmen learn CUPL, the Cornell computing language, while enrolled in this latter course, and make subsequent use of it in their mathematics, science, and engineering courses.

During the sophomore year the core includes further work in mathematics and physics and a liberal studies course in each term for all students. To round out the sophomore year, two engineering science courses are chosen by a student each term. It is intended that these serve as the mechanism linking his work in mathematics and sciences with studies in the upperclass engineering program.

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 two additional engineering science sequences, twelve credit hours of liberal 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 into one of these fields, the student should select the appropriate engineering science courses during the sophomore year (see the Basic Studies curriculum, page 27). Approximately 30 percent of the four-year program is devoted to professional studies of a chosen field.

At the completion of the four-year *Field Program,* a graduate 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 industry.

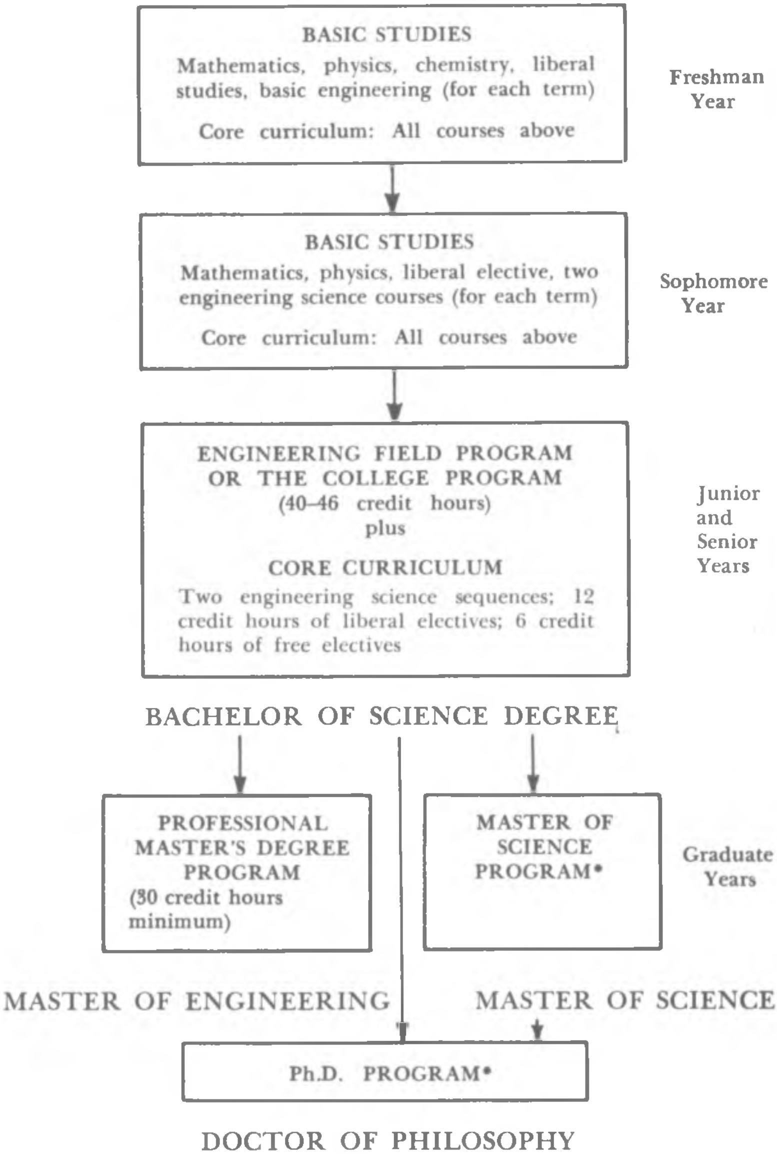
Individuals seeking careers in research in applied science or in a specialized engineering area, such as thermal engineering within mechanical engineering, can apply for the Master of Science or the Doctor of Philosophy program at the end of the four-year Bachelor's program. Some students may want to undertake graduate or professional study in other fields such as law, business, public administration, or medical research. 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.

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.

Companies participating in the Engineering Cooperative Program include the following: American Electric Power Service Corporation; Anaconda Wire and Cable Company; Campbell Soup Company; Cornell Aeronautical Laboratory; Eastman Kodak Company; Emerson Electric Company; Farrel Corporation; General Electric Company; General Radio Company; Gleason Works; Hewlett-Packard (Sanborn

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.

Division); International Business Machines Corporation; Moore Products Co.; The National Cash Register Company; Raytheon Company; Sanders Associates, Inc.; United Air Lines; and 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, for example, can 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. Although he earns a substantial salary while on assignment, more important is the 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, 109–110 Phillips Hall.

CONTINUING EDUCATION ACTIVITIES

The Office of Continuing 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.

A four-week course entitled "Modern Engineering Concepts for Technical Managers" is offered annually. It consists of a series of sixty-four lecture-seminars which include topics in materials science, mathematics, operations research, electronics and solid-state devices, communication theory, bioengineering, nuclear science, and other areas. The course emphasizes breadth, not depth, and provides a structure for technological achievement and a resource from which to draw ideas and direction for effective technical management. A similar course is planned as a general offering in the 1969 summer program.

Courses in materials science and engineering statistics, some carrying academic credit, have been given to industrial personnel by means of long-distance telephone communications via an electronic "Blackboard-by-Wire" system. The professor lectures at Cornell; his voice and writing are carried by telephone to classrooms at the industrial plants.

Intensive short courses, one to two weeks long, are offered in various technical subjects each summer. Twenty-one courses were offered in 1968; the subjects included programming languages, optimization, statistics, operations research, structural mechanics, energy conversion, microscopy, chemical reactor design, mechanical analysis, and other topics. Participants in these courses are drawn from many different states and foreign countries.

A long-term program in construction engineering and administration, funded in part by the United States Department of Commerce, provides three 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.

The New York State Technical Services Program, supported by the State and Federal Departments of Commerce, provides technical assistance to the smaller manufacturing firms of the New York State Southern Tier. Activities under this program include a technical referral service; asistance in defining technical problems; dissemination of technical information and news; and lectures, workshops, and seminars which vary from one to four days in length, on topics of interest to area industry.

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

ADMISSION

Detailed information concerning the methods and procedures of undergraduate admission is given in the *Announcement of General Information.*

REQUIREMENTS FOR ADMISSION AS AN UNDERGRADUATE

Secondary School Credits

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

Subject	*Units*[1]
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

[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 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

Applicants will be admitted to the College of Engineering who, in all essential respects, have demonstrated a high order of scholastic achievement and who, so far as can be determined, have a well-considered desire to study engineering. They must possess positive characteristics of work and study and the maturity necessary to meet the demands of living successfully in an active and stimulating university environment. Good grades or high College Board scores are in themselves no guarantees of success or even of admission. High motivation and the desire to succeed are equally important.

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 and Special Students

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.

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 required time to complete the course must have had some engineering training, and must satisfy the prerequisites for the courses they wish to take. Others with a baccalaureate degree 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, Edmund Ezra Day Hall.

REQUIREMENTS FOR ADMISSION TO THE GRADUATE DEGREE PROGRAMS

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 degrees—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 Masters' Degrees

Professional degrees at the Master's level are offered in aerospace, agricultural, chemical, civil, and electrical engineering, industrial engineering and operations research, materials science and engineering, 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 wish to enhance their ability in the practice of 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 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.

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 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 $3,600 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	$2000
Charles R. Armington Scholarship	Any	6	Up to $2000
John Henry Barr Scholarship	Any	1	Up to $2000
Seymour L. Baum Memorial Fund	Electrical Engineering	1	$200
Robert H. Blackall Scholarship	Any	3	$1250*
Edward P. Burrell Scholarship Endowment	Any	10	$1300*
Carrier Memorial Scholarship	Any	3	$1200
Chrysler Corporation Scholarship	Any	5	$500
Redmond Stephen Colnon Scholarship Endowment	Any	1	$1500
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*

* Range variable. Figure given is the mean average.

Donor	*Designated Engineering Field*	*Total Number of Awards*	*Amount per Award*
Joseph H. Evans Endowment	Any	1	$250
C. Harold Fahy Scholarship Endowment	Civil Engineering	1	$700
Elbert Curtiss Fisher Scholarship	Any	1	$1200
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 $2200
Paul G. Haviland Memorial Scholarship	Any	1	$1000
Howard Elmer Hyde Civil Engineering Scholarship	Civil Engineering	1	$300
Martin J. Insull Scholarship Endowment	Any	2	$1100*
Albert Jadot Memorial Scholarship Endowment	Foreign Students	1	$600
Lockheed National Scholarship	Any	4	$2700
Chester H. Loveland Engineering Scholarship Fund	Civil Engineering	1	Up to $1550
The Charles McAllister '87 Endowment	Any	1	$350
Harrison D. McFaddin Scholarship Endowment	Any	4	$1000*
John McMullen Scholarship Fund	Any	300*	$1700*
Minnesota Mining and Manufacturing Company Undergraduate Scholarship	Any	1	$1200
Monsanto Chemical Company Scholarship	Chemical Engineering	1	$1000
Robert C. Newcomb Scholarship Fund	Any	3	$950*
Niagara Machine and Tool Works Scholarship	Mechanical Engineering	1	$1000
Owens-Illinois Scholarship	Any	4	$2350
Frank William Padgham Scholarship Endowment	Mechanical Engineering	1	$200
Annie F. and Oscar W. Rhodes Scholarship Endowment	Any	15	$1100*
Huldah Jane Rice Scholarship Endowment	Any	5	$1800*
Rohm and Haas Scholarship	Chemical Engineering	1	$1000
Scott Paper Company Foundation Award	Any	2	$1000
Frederick B. Scott Scholarship Fund	Any	1	$1000
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	$1725

Donor	Designated Engineering Field	Total Number of Awards	Amount per Award
Stauffer Chemical Company Scholarship	Chemical Engineering	1	$1000
William Delmore Thompson Scholarship Endowment	Mechanical Engineering	1	$100
Universal Oil Products Foundation Scholarship	Various Specified Fields	2	Up to $1000
Leon C. Welch Scholarship Fund	Any	1	$800
John L. Wentz Scholarship Endowment	Any	1	$400
Western Electric Fund Scholarship	Any	2	$1000
Henry G. White Scholarship	Civil Engineering	1	$2000
Jessel Stuart Whyte Scholarship Endowment	Mechanical Engineering	2	$1500*
Wilson Endowment	Mechanical and Electrical Engineering	1	$300
Wyman-Gordon Company Scholarship	Materials Science and Engineering	1	$1000

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 $500,000.

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.*

STUDENT LIFE AT CORNELL

HOUSING

University residence halls, located a convenient distance from academic buildings, libraries, and other campus facilities, provide accommodations for approximately 2,000 undergraduate men. Nearly all freshmen reside in dormitories; upperclassmen may reside either in dormitories, in fraternity houses, or in off-campus rooms or apartments. Dining facilities are provided in several locations throughout the campus.

Housing facilities for undergraduate women, graduate students, and married students are also available. Consult the *Announcement of General Information* for further details.

UNIVERSITY ACTIVITIES

Cornell offers students the opportunity to participate in a varied program of extracurricular activities. Something can be found to meet nearly every interest, including student government, athletics, publications, music, dramatics, and various social and cultural organizations.

The intercollegiate athletic program is the largest in the country, with competition in twenty-two sports. In addition, the various athletic facilities are available for intramural and informal competition.

Throughout the year, there are opportunities to hear lectures by distinguished visitors to the campus. Concerts and dramatic performances are offered, both by University groups and by outside artists. Art of various forms is on display at the Andrew Dickson White Museum of Art, the Art Room of Willard Straight Hall, and other galleries on campus.

Cornell students publish a full-scale, daily newspaper, the *Cornell Daily Sun,* a yearbook, and several literary and humor magazines. The campus radio station, WVBR, is operated entirely by students.

There are international and political clubs, service clubs, professional and departmental societies, and clubs devoted to a wide assortment of hobbies.

RELIGIOUS AFFAIRS. Although Cornell has been a nonsectarian institution from its founding, it has a center for the coordination and sponsorship of religious activities. A staff of twelve University chaplains represent the major religious denominations. Thus facilities and personnel for religious study, worship, counsel, and fellowship are available. In addition, each Sunday distinguished visiting clergymen from all over the world conduct interdenominational services in Sage Chapel.

HEALTH SERVICES. Health services and medical care are available at Cornell's Gannett Clinic and Sage Hospital (a fully accredited hospital). Student fees cover treatment and care at the Clinic and Hospital, with up to two weeks of hospitalization per term. Consult the *Announcement of General Information* for details.

PHYSICAL EDUCATION. All freshmen and sophomores are required to take physical education. The freshman program includes activity in each of six sports, while in the sophomore year a student concentrates on one or two sports.

OFFICER EDUCATION. The Army, Navy, and Air Force all offer ROTC programs at Cornell. Participation is voluntary, and successful completion of the program results in a commission in the chosen service. For further information, consult the *Announcement of Officer Education.*

HONOR SOCIETIES. Engineering students may qualify for membership in local and national honor societies, including Tau Beta Pi, Phi Kappa Phi, Sigma Xi, Pi Tau Sigma, Chi Epsilon, Rod and Bob-Pyramid, Atmos, Kappa Tau Chi, and Eta Kappa Nu.

STUDENT PUBLICATION. The *Cornell Engineer*, a magazine containing articles of professional interest for engineering students and alumni, is published throughout the academic year by undergraduates of the College of Engineering.

ENGINEERING SOCIETIES. Many meetings of the American Society of Civil Engineers, American Institute of Industrial Engineers, American Society of Mechanical Engineers, American Institute of Electrical Engineers, Society of Automotive Engineers, and Institute of Electrical and Electronic Engineers are held on campus and are attended by students. The College also maintains active student branches of these societies, as well as of the American Institute of Chemical Engineers, American Society of Agricultural Engineers, and the American Institute of Aeronautics and Astronautics. The Cornell Metallurgical Society was formed in 1949 and is an affiliate of the American Institute of Mining and Metallurgical Engineers. A student branch of the American Nuclear Society was founded in 1959.

ENGINEERING STUDENT COUNCIL. The Engineering Student Council, consisting of elected student representatives from each division of the College, plans the annual Engineers' Day program for high school visitors to the campus and represents student viewpoints in campus affairs. Upperclassmen on the Council have participated in an informal tutoring program for freshmen desiring such assistance.

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 and Study Skills Center, the Educational-Vocational Guidance Office, Cornell United Religious Work, the University Placement Service, and the Office of Scholarships and Financial Aid.

For planning and scheduling his academic work each engineering student is assigned an adviser. The adviser should usually be the first person consulted in all matters of student counseling and should always be consulted on questions of curriculum, academic standards, or scholastic performance. In addition, students are free to confer with the dean, directors, and other faculty members on any educational or personal matters.

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.

It is a source of information on all personnel services to students, and any student is welcome to consult the Director of the Office on non-academic matters. Special provision is made for questions relating to financial aid and placement.

Placement

The facilities of the University Placement Service 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. Members of the engineering faculty are assigned as placement advisers with whom students may discuss their career objectives, whether for employment or graduate study. Information about companies is available both in the Placement Service and the Office of Student Personnel, 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 Basic Studies Division is responsible for the freshman and sophomore curricula in the College.

HOLLISTER HALL

Mr. H. G. Smith, Director.

Freshmen in the College of Engineering are enrolled for the first two years of their undergraduate program in the Division of Basic Studies of the College of Engineering. The Division supervises admissions to the College at the underclass level, administers a program of courses for freshmen and sophomores, and assigns to each engineering underclassman a senior member of the College of Engineering faculty as his adviser.

The freshman year program includes studies in mathematics, physics, chemistry, and a liberal elective. Through contact with senior engineering staff, both as advisers and in class discussions in the freshman introductory courses, the student is made more fully aware of the range of opportunities in the engineering profession. Understanding graphics as a form of technical communication and the use of modern digital computing machines are particular skills developed in all freshman engineering students.

During the sophomore year, the engineering student continues his work in mathematics and physics and begins to integrate these sciences with two engineering science courses taught by members of the faculty of the College of Engineering. Included also is a liberal studies elective (liberal studies constitute approximately one-fifth of the engineering curriculum at Cornell). Students who anticipate enrollment in chemical engineering establish earlier chemistry sequences during their sophomore program.

Most students begin to select their upperclass objectives before the beginning of the fall term of their sophomore year. Each professional school specifies two engineering science courses. This requirement may alternatively be taken either during the fall and spring terms of the sophomore year or in the spring term and summer session preceding the junior year. Through these options, a student still has a choice among several engineering fields as late as the beginning of the junior year.

If a student expresses interest in a particular branch of engineering at the outset, he will be assigned to a faculty adviser whose major interest is in that field. Otherwise, after he determines his field of study he may change his adviser to obtain the counsel of a faculty member in his chosen field.

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 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 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 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. All engineering students are required to complete twenty-four hours of liberal studies before graduation; twelve hours of liberal electives must be completed by students in this Division as part of the College requirement.

Freshman Year

Freshman students entering the College of Engineering in the fall of 1968 will take the following program of courses:

		Contact Hours	
TERM 1	*Credit Hours*	*Lec. Rec.*	*Lab. Comp.*
Mathematics 191 or 193, Calculus for Engineers	4	3	2
Physics 121, Introductory Analytical Physics I	3	3	2
Chemistry 107, General Chemistry	3	2	3
Freshman Humanities	3	3	0
Engineering 103, Engineering Graphics and Design	3	2	2½
or			
Engineering 104, Introduction to Engineering	3	2	2½

	Contact Hours		
	Credit Hours	Lec. Rec.	Lab. Comp.
TERM 2			
Mathematics 192 or 194, Calculus for Engineers	4	3	2
Physics 122, Introductory Analytical Physics II	3	3	2
Chemistry 108, General Chemistry	4	3	3
Freshman Humanities	3	3	0
Engineering 103, Engineering Graphics and Design	3	2	2½
or			
Engineering 104, Introduction to Engineering	3	2	2½

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

Sophomore Year

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

	Credit Hours	Lec. Rec.	Lab. Comp.
TERM 3			
Mathematics 293 or 293H, Engineering Mathematics	4	4	0
Physics 233, Introductory Analytical Physics III	3	4	0
and			
Physics 235, Introductory Analytical Physics, Laboratory	1	0	2
or			
Physics 237, Introductory Analytical Physics III, Honors	4	4	2½
Liberal Elective*	3 or 4	–	–
Engineering Sciences (two of following)	6 or 7	–	–
Materials Science 6210	(3)	(2)	(2)
Electrical Science 241	(3)	(3)	(0)
Mechanics 211	(4)	(3)	(2)

* See footnote page 30.

		Contact Hours	
	Credit Hours	*Lec. Rec.*	*Lab. Comp.*
TERM 4			
Mathematics 294 or 294H, Engineering Mathematics	3	3	0
Physics 234, Introductory Analytical Physics IV	3	4	0
and			
Physics 236, Introductory Analytical Physics, Laboratory	1	0	2
or			
Physics 238, Introductory Analytical Physics IV, Honors	4	4	2½
Liberal Elective*	3 or 4	–	–
Engineering Sciences (two of following)	6 or 7	–	–
Materials Science 6211	(3)	(2)	(2)
Electrical Science 242	(3)	(3)	(0)
Mechanics 212	(4)	(3)	(2)

* See footnote page 30.

Each upperclass Field Program specifies two engineering sciences which must be successfully completed in order to enroll in the program at the beginning of the junior year. The specific Field Program requirements are as follows:

Civil Engineering	Mechanics 211–212
	Preferably Materials Science 6210–6211
Electrical Engineering	Electrical Science 241–242
	Mechanics 211–212
Engineering Physics	Electrical Science 241–242
	Materials Science 6210–6211
Industrial Engineering and Operations Research	Any two
	Preferably Mechanics 211–212, Materials Science 6210–6211
Materials Science and Engineering	Mechanics 211–212
	Materials Science 6210–6211
Mechanical Engineering	Mechanics 211–212
	Preferably Materials Science 6210–6211

Mechanics, electrical science, and materials science will be offered from fall through summer: Mechanics 211 in the fall and spring, and Mechanics 212 in the spring and summer; Electrical Science 241 in the fall and spring, and Electrical Science 242 in the spring and summer; Materials Science 6210 in the fall and spring, and Materials Science 6211 in the spring and summer.

All sophomore engineering students indicating a preference for chemical engineering will take the following program of courses:

TERM 3	Credit Hours	Contact Hours Lec. Rec.	Contact Hours Lab. Comp.
Mathematics 293 or 293H, Engineering Mathematics	4	4	0
Physics 233, Introductory Analytical Physics III	3	4	0
and			
Physics 235, Introductory Analytical Physics, Laboratory	1	0	2
or			
Physics 237, Introductory Analytical Physics III, Honors	4	4	2½
Chemistry 287, Introductory Physical Chemistry	3	3	0
and			
Chemistry 289, Introductory Physical Chemistry Laboratory	2	1	6
Chemical Engineering 5101, Mass and Energy Balances	3	3	2
Liberal Elective*	3 or 4	–	–

TERM 4	Credit Hours	Contact Hours Lec. Rec.	Contact Hours Lab. Comp.
Mathematics 294 or 294H, Engineering Mathematics	3	3	0
Physics 234, Introductory Analytical Physics IV	3	4	0
and			
Physics 236, Introductory Analytical Physics, Laboratory	1	0	2
or			
Physics 238, Introductory Analytical Physics IV, Honors	4	4	2½
Chemistry 288, Introductory Physical Chemistry	3	3	0
and			
Chemistry 290, Introductory Physical Chemistry Laboratory	2	1	6
Chemical Engineering 5102, Equilibria and Staged Operations	3	3	2
Liberal Elective*	3 or 4	–	–

* Liberal electives include courses in social sciences, history, humanities, modern foreign languages, and expressive arts (courses such as accounting, management, and law excluded) chosen from a list approved by the Core Curriculum Committee. A total of twenty-four credit hours are reserved for liberal studies, and at least six of the credit hours in upperclass courses. No more than six liberal credit hours may be earned in a modern foreign language.

In addition to the twenty-four credit hours for liberal studies, there are six credit hours for free electives. To satisfy this requirement, a student may take any course at the University to which he can gain admission.

AEROSPACE ENGINEERING

DEGREES OFFERED: Master of Engineering (Aerospace); Master of Science; Doctor of Philosophy.

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 III, 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 especially 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, and other areas. Students and staff also carry out highly theoretical investigations in such 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 space vehicles which leave and re-enter planetary atmospheres at extreme speeds. Research work may also be carried out in other related disciplines of mutual interest to the student and advising professors.

Preparation for Graduate Study

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

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, electricity and magnetism, etc.

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 Director of the Graduate School of Aerospace Engineering, Grumman Hall. A special application blank for this purpose can be obtained from the Director's office. It should be returned directly to him. Candidates for an advanced degree in this field who do not already hold the Master's degree are encouraged to matriculate first as candidates for this 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 generally will 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 or examinations in the subjects listed below. The subject list constitutes a standard of accomplishment for the Master of Engineering (Aerospace) candidate, but the faculty may modify the list to suit the needs, interests, and background of each individual candidate. 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 pages 102–104) 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.

Course Sequences Available for Master of Engineering (Aerospace)

	Hours
7101–02, Advanced Kinetic Theory, Gasdynamics	6
7201–02, Introductory Plasmadynamics, Introductory Magnetohydrodynamics	6
7301–02, Fluid Mechanics, Aerodynamics	
1171, 1172, Artificial Satellite Theory, Space Flight Mechanics	6
2730, Aerospace Structural Analysis and one three-credit hour elective course	6

Electives: List A[1]

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

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

Electives: List B

1162, Vibration of Elastic Systems	4
1163, Applied Elasticity	3
1164, Theory of Elasticity	3
1165, Mathematical Theory of Elasticity	3
1170, Advanced Dynamics	3
1175, Nonlinear Vibrations	3
3652, Combustion Theory	3
3674, Statistical Thermodynamics	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

	Hours
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

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 degrees 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, etc. The programs are extremely broad in order to accommodate the widest interests of the students and the broadest needs of the industry.

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 may obtain them by writing to the Director of the School, Grumman Hall.

AGRICULTURAL ENGINEERING

DEGREES OFFERED: Bachelor of Science; Master of Engineering (Agricultural); Master of Science; Doctor of Philosophy.

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 College 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 which 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, 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.

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.

Practice Requirement

Since agricultural engineering students are registered in the College of Agriculture for the first three years, they must meet the practice requirement of that College. The basic requirement is thirteen units of acceptable farm experience gained at the approximate rate of one unit per week. Eight of these units must be completed before registration for the sophomore year. The entire thirteen units must be completed prior to registration in the third year. *The Announcement of the College of Agriculture* should be consulted for details of the requirement.

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.*

		Contact Hours	
TERM 1	*Credit Hours*	*Lec. Rec.*	*Lab. Comp.*
Mathematics 191, Calculus for Engineers	4	4	0
Physics 121, Introductory Analytical Physics I	3	3	2½
Chemistry 103, Introduction to Chemistry	3	2	3
or			
Chemistry 107, General Chemistry	3	2	3
or			
Chemistry 115, General Chemistry and Inorganic Qualitative Analysis	4	3	3
Freshman Humanities	3	–	–
Agr. Engineering 153, Engineering Drawing	3	2	3½
Agriculture 101, Orientation	1	1	0
Total	17–18		

	Credit Hours	Contact Hours Lec. Rec.	Contact Hours Lab. Comp.
TERM 2			
Mathematics 192, Calculus for Engineers	4	4	0
Physics 122, Introductory Analytical Physics II	3	3	2½
Chemistry 104, Introduction to Chemistry	3	2	3
or			
Chemistry 108, General Chemistry	4	3	3
Chemistry 116, General Chemistry and Inorganic Qualitative Analysis	4	2	6
Freshman Humanities	3	3	0
Agr. Engineering 152, Introduction to Agricultural Engineering Measurement	3	1	5
Total	16–17		

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

	Credit Hours	Lec. Rec.	Lab. Comp.
TERM 3			
Mathematics 293, Engineering Mathematics	4	4	0
Physics 233, Introductory Analytical Physics III	3	3	0
Physics 235, Introductory Analytical Physics, Laboratory	1	0	2
Engineering 211, Mechanics of Rigid and Deformable Bodies I	4	3	2½
Biological Sciences 101, General Biology	3	3	3
or			
Biological Sciences 103, Plant and Animal Biology	3	2	3
Engineering 6210, Materials Science	3	2	2½
Total	18		

	Credit Hours	Contact Hours Lec. Rec.	Lab. Comp.
TERM 4			
Mathematics 294, Engineering Mathematics	3	3	0
Physics 234, Introductory Analytical Physics IV	3	3	0
Physics 236, Introductory Analytical Physics, Laboratory	1	0	2
Engineering 212, Mechanics of Rigid and Deformable Bodies II	4	3	2½
Biological Sciences 102, General Biology	3	3	3
or			
Biological Sciences 104, Plant and Animal Biology	3	2	3
Engineering 6211, Materials Science	3	2	2½
Total	17		

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

	Credit Hours	Lec. Rec.	Lab. Comp.
TERM 5			
Engineering 3631, Thermodynamics	3	3	0
Agronomy 200, Nature and Properties of Soils	4	3	2½
Liberal Elective	3	–	–
Communication Arts 301, Oral Communication	2	–	–
Agr. Engineering 462, Agr. Power*	3	2	2½
Engineering 2701, Structural Theory*	3	2	2
Total	18		

	Credit Hours	Lec. Rec.	Lab. Comp.
TERM 6			
Engineering 3632, Fluid Mechanics	3	3	0
Technical Elective	3	–	–
Liberal Elective	3	–	–
Engineering 3331, Kinematics and Components of Machines	3	2	2½
Agr. Engineering 471, Soil and Water Engineering†	3	2	2½
Agr. Engineering 481, Agr. Structures†	3	2	2½
Total	18		

* † See footnotes at end of the Bachelor of Science Program.

	Credit Hours	Contact Hours Lec. Rec.	Lab. Comp.
TERM 7			
Animal Science 100, or 112 or 250*	3–4	2–3	2½
Engineering 4941, Introductory Electrical Engineering	3	2	2½
Agronomy 111, Introduction to Crop Science	4	3	2½
Liberal Elective	3	–	–
Elective	3	–	–
Total	16–17		
TERM 8			
Agr. Economics 302, Farm Management	5	3	2½
Engineering 4942, Introductory Electrical Engineering	3	2	2½
Agr. Engineering 461, Agr. Machinery Design†	3	2	2½
Agr. Engineering 463, Processing and Handling Systems for Agr. Materials†	4	3	2½
Agr. Engineering 450, Special Topics in Agr. Engineering	1	1	0
Liberal Elective	3	–	–
Total	19		
Total for eight terms	139–142		

* Agr. Engineering 462, Agr. Power, and Engineering 2701, Structural Theory, are taken either in the fifth or seventh terms, alternating with Agronomy 111, Field Crops, and Animal Science.

† Agr. Engineering 463, Processing and Handling Systems, and Agr. Engineering 461, Agr. Machinery Design, are taken either in the sixth or eighth terms, alternating with Agr. Engineering 481, Agr. Structures, and Agr. Engineering 471, Soil and Water Engineering.

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 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 sub-areas of agricultural engineering or take a broad program without specialization. The sub-areas 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, and soil engineering.

MASTER OF SCIENCE AND DOCTOR OF PHILOSOPHY DEGREES

Flexible programs leading to both the M.S. and Ph.D. are offered in the following areas of specialization for either a major or 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. Several assistantships are available with annual stipends that are comparable to those offered at other Land Grant institutions. For more detailed information write the Graduate Field Representative, Riley-Robb Hall.

APPLIED PHYSICS

DEGREES OFFERED: Master of Science; Doctor of Philosophy.

CLARK HALL

Mr. N. Rostoker, Chairman; Messrs. B. W. Batterman, K. B. Cady, D. D. Clark, R. K. Clayton, D. R. Corson, T. R. Cuykendall, H. H. Fleischmann, P. L. Hartman, J. A. Krumhansl, R. McPherson, M. Nelkin, H. G. Newhall, E. L. Resler, Jr., T. N. Rhodin, H. S. Sack; Mrs. M. Salpeter; Messrs. B. M. Siegel, J. Silcox, W. W. Webb, G. J. Wolga. Visiting Staff: Messrs. I. Kuščer, A. Ron.

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, C. Lee, C. Y. Li, R. L. Liboff, P. R. McIsaac, A. L. Ruoff, D. N. Seidman, R. N. Sudan, C. L. Tang, A. Taylor, D. L. Turcotte.

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 broad 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 bulletins available from Field Representative, Applied Physics, Clark Hall.

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, and theoretical studies of plasma instabilities, molecular dynamics in fluids, and the statistical physics of phase transitions in quantum fluids. These topics represent just a few of the interesting variety of timely topics 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.

OLIN HALL

Mr. C. C. Winding, 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, R. York. Visiting Staff: Messrs. P. G. Ashmore, P. H. Calderbank.

Chemical engineering involves the application of the principles of the physical sciences and of mathematics, and of engineering judgment to fields in which matter is treated to effect a change in state, energy content, or chemical composition. Most chemical engineers are employed in the process industries. In these industries, raw materials are converted into useful products such as industrial chemicals, petroleum products, metals, rubbers, plastics, synthetic fibers, foods, paints, and paper.

Preparation for professional work in chemical engineering has always involved a five-year program at Cornell. The present program in which a student receives a Bachelor of Science degree at the end of four years and the degree Master of Engineering (Chemical) at the end of the fifth year is based on over thirty years of experience with five-year programs. The curriculum that has evolved applies the latest developments in the fields of mathematics, chemistry, physics, and the engineering sciences to chemical engineering concepts in order to develop competence in professional work. Graduates of the five-year program are prepared to start their professional engineering careers or continue in graduate programs leading to doctoral degrees.

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. A large model shop is used to construct scale models of plant designs.

The Degree Programs

The five-year professional program leading to the degree of Master of Engineering (Chemical) provides a coordinated sequence of chemical engineering courses starting in the second year and extending through the fifth year. Mathematics, physics, mechanics, and electrical science are common with the other divisions of the Engineering College, but the need for greater breadth and depth in chemistry requires additional courses taught by the Chemistry Department. The courses in chemical processes, materials science, and thermodynamics require sound preparation in chemistry and form an important part of specialized chemical engineering training.

Course programs for Terms 1 through 4, administered by the Division of Basic Studies, are described on pages 27–29. Although the student planning to enroll in the five-year 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, 5102 during the sophomore year.

BACHELOR OF SCIENCE

TERM 5	*Credit Hours*	*Contact Hours* *Lec. Rec.*	*Lab. Comp.*
Chemistry 357, Introductory Organic Chemistry	3	3	0
Chemistry 355, Elementary Organic Laboratory	2	0	6
Engineering 5303, Analysis of Stage Processes	3	2	2
Engineering 211, Mechanics of Rigid and Deformable Bodies I	4	3	2½
Engineering 5851[1], Chemical Microscopy	3 or 0	1	5
Liberal Elective(s)	3 or 6	–	–
Total	18		

[1] If included in Term 5, student elects one liberal studies course in each of Terms 5 and 6; if included in Term 6, student elects two liberal studies courses in Term 5 and none in Term 6.

	Credit Hours	Contact Hours Lec. Rec.	Lab. Comp.
TERM 6			
Chemistry 358, Introductory Organic Chemistry	3	3	0
Chemistry 356, Elementary Organic Laboratory	2	0	6
Engineering 5304, Introduction to Rate Processes	3	2	2
Engineering 5203, Chemical Processes	4	4	0
Engineering 212, Mechanics of Rigid and Deformable Bodies II	4	3	2½
Engineering 5851, Chemical Microscopy	0 or 3	1	5
Liberal Elective	3 or 0	–	–
Total	19		
TERM 7			
Engineering 5106, Reaction Kinetics and Reactor Design	3	2	2
Engineering 5353, Unit Operations Laboratory	3	2	3
Engineering 5742, Polymeric Materials	3	3	0
Engineering 4941, Introductory Electrical Engineering	3	3	0
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	18		
TERM 8			
Engineering 5103, Chemical Engineering Thermodynamics	3	2	2
Engineering 5354, Project Laboratory	3	1	5
Engineering 5256, Materials	4	4	0
Engineering 4942, Introductory Electrical Engineering	3	3	0
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	19		
Total for eight terms	144–147		

MASTER OF ENGINEERING (CHEMICAL)

	Credit Hours	Contact Hours Lec. Rec.	Contact Hours Lab. Comp.
TERM 9			
Engineering 5621, Process Design and Economics	6	4	4
Engineering 1150, Advanced Engineering Analysis	3	3	0
Technical Electives	6	–	–
Total	15		
TERM 10			
Engineering 5622, Process and Plant Design	6	4	4
Engineering 5717, Process Control	3	2	2½
Chemical Engineering Elective	3	–	–
Technical Electives	3	–	–
Total	15		

OPTIONS

Specialized work is offered in biochemical engineering, polymeric materials, process control, reaction kinetics, process and plant design, and process economics. The free electives in the seventh and eighth terms and the nine credits of technical electives in the professional Master's degree program permit a student to select a maximum of fifteen credit hours in other divisions of the Engineering College or the University. This choice of electives at an advanced level allows students to arrange programs that are the equivalent of options in either the specializations mentioned above or in other fields such as nuclear engineering, industrial engineering, chemistry, economics, and business administration. The exact sequence of courses to be selected for advanced training is not specified, since it depends on the student's interests and capabilities.

THE COLLEGE PROGRAM: MAJORS AND MINORS

Students pursuing the four-year *College Program,* described on page 53, 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 are expected to complete a Master of Science degree during their fifth year rather than the Master of Engineering (Chemical) program. During the fourth year, a research project is begun in place of the project-laboratory course which is required otherwise. This research continues throughout the fifth year to meet the thesis requirement for the M.S. degree. The electives available during the fourth and fifth year permit the completion of one Ph.D. minor and a start on the second minor. 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. The actual courses required during the fourth year in the B.S. program and the fifth year leading to the M.S. are outlined below.

		Contact Hours	
TERM 7	*Credit Hours*	*Lec. Rec.*	*Lab. Comp.*
Engineering 5106, Reaction Kinetics and Reactor Design	3	2	2
Engineering 5353, Unit Operations Laboratory	3	2	3
Engineering 5742, Polymeric Materials	3	3	0
Engineering 5909, Research Seminar	0	1	0
Engineering 4941, Introductory Electrical Engineering	3	3	0
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	18		

	Credit Hours	Contact Hours Lec. Rec.	Lab. Comp.
TERM 8			
Engineering 5103, Chemical Engineering Thermodynamics	3	2	2
Engineering 5952, Research Project	3	0	9
Engineering 5256, Materials	4	4	0
Engineering 4942, Introductory Electrical Engineering	3	3	0
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	19		
TERM 9			
Engineering 5505, Advanced Transport Phenomena	4	4	0
Engineering 5900, Seminar	1	1	0
Elective	3	0	0
Minor Courses	3	–	–
Total	11		
TERM 10			
Engineering 5717, Process Control	3	2	2½
Engineering 5506, Advanced Transport Phenomena	4	4	0
Engineering 5900, Seminar	1	1	0
Minor Courses	6	–	–
Total	14		

In addition, students will continue their research project throughout terms 9 and 10. Credit hours and grades are not granted for thesis research.

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 requires the successful completion of thirty credit hours of specified courses as outlined on page 44. This M.Eng. (Chemical) degree is awarded for the successful completion of the five-year professional program in chemical engineering at Cornell, but students from other institutions may also be awarded this degree if they have the proper prerequisites and complete the required thirty credit hours.

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 satisfactory thesis involving individual or original research or investigations. A student interested in these degrees should consult the *Announcement of the Graduate School: Physical Sciences.* For a description of the research interests of the staff of the School of Chemical Engineering, write the Graduate Field Representative in Chemical Engineering, Olin Hall.

CIVIL ENGINEERING

DEGREES OFFERED: Bachelor of Science; Master of Engineering (Civil); Master of Science; Doctor of Philosophy.

HOLLISTER HALL

Mr. W. L. Hewitt, Acting Director; Messrs. V. C. Behn, D. J. Belcher, G. H. Blessis, W. Brutsaert, L. B. Dworsky, S. J. Errera, M. I. Esrig, L. M. Falkson, G. P. Fisher, R. Gallagher, C. D. Gates, P. Gergely, D. J. Henkel, A. W. Lawrence, T. D. Lewis, T. Liang, J. A. Liggett, R. C. Loehr, D. P. Loucks, W. R. Lynn, G. B. Lyon, W. McGuire, A. J. McNair, A. H. Nilson, C. S. ReVelle, R. G. Sexsmith, F. O. Slate, S. Stidham, Jr., R. N. White, G. Winter. Visiting Staff: Messrs. P. Baron, B. LeLievre, G. Terzidis.

Civil Engineering deals primarily with the large fixed works, systems, and facilities that are basic to community living, industry, and commerce and vital to the welfare of man. 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 and to city planning. 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 page 51)
Geotechnical Engineering (See page 52)
Structural Engineering (See page 52)
Water Resources Engineering (See page 53)

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 or Doctor of Philosophy. These degrees are intended primarily for students who plan a career 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 pages 27–29 of this *Announcement*. The Division of Basic Studies program specifies that two engineering science courses be taken in each term of the sophomore year. Mechanics 211 and 212 are required for entry into the Civil Engineering Field Program. It is recommended, but not required, that students planning to enter civil engineering take Materials Science 6210 and 6211 as their other sophomore engineering science courses.

TERM 5	Credit Hours	Contact Hours Lec. Rec.	Lab. Comp.
Engineering 2701, Structural Engineering I	3	2	2
Engineering 2301, Fluid Mechanics	3	3	–
Geology 203, Geology for Engineers	3	2	3
Engineering 9170, Introductory Engineering Statistics	3	2	2½
Engineering 4941, Introductory Electrical Engineering	3	2	2½
Liberal Elective	3	–	–
Total	18		

TERM 6	Credit Hours	Lec. Rec.	Lab. Comp.
Engineering 2751, Engineering Materials	3	2	2½
Engineering 2702, Structural Engineering II	3	2	2
Engineering 2451, Engineering Measurements	3	2	2½
Engineering 2302, Hydraulic Engineering	3	2	2½
Engineering 4942, Introductory Electrical Engineering	3	2	2½
Liberal Elective	3	–	–
Total	18		

TERM 7	Credit Hours	Lec. Rec.	Lab. Comp.
Engineering 2703, Structural Engineering III	3	2	2
Engineering 2401, Elements of Soil Mechanics	3	2	2½
Engineering 2501, Water Supply and Waste-Water Engineering	3	2	2½
Engineering 2601, Transportation Engineering	3	2	2½
Engineering 3631, Thermodynamics	3	3	–
Liberal or Free Elective	3	–	–
Total	18		

TERM 8	Credit Hours	Lec. Rec.	Lab. Comp.
Engineering 2603, Engineering Economy	3	3	–
Civil Engineering Electives	6	–	–
Liberal Electives*	3 or 6	–	–
Free Electives†	6 or 3	–	–
Total	18		

* One course if Liberal Elective was taken in Term 7.
† One course if Free Elective was taken in Term 7.

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 page 53). 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 requirement for which are stated on page 18. 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 is 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 and 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. G. H. Blessis, L. M. Falkson, T. D. Lewis, W. R. Lynn, C. S. ReVelle, S. Stidham, Jr. Visiting Staff: P. Baron.

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 and massive technological problems of modern society which fall predominantly in the area of civil engineering. It is concerned with methods of allocation of resources in the public sector 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 systems; engineering and construction project management; solid waste disposal; and public health 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 inter-modal transfer efficiency, river basin studies, rationalization of complex construction projects, optimal location of transportation links and public facilities, and to 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, Geotechnical Engineering, Structural Engineering, Water Resources Engineering, and with many other areas of the University, students are encouraged to take advantage of a large variety of ancillary course offerings that support the general program of study.

Undergraduates may concentrate in this subject area by electing the *College Program* and framing a course of study with the assistance of the Department. Graduate studies in transportation engineering, construction project management, and urban systems are conducted primarily by the Department of Environmental Systems Engineering. Master of Science and Doctor of Philosophy candidates majoring in Environmental Systems Engineering follow graduate programs comprising systems analysis, economics, and a specific application area such as those aforementioned.

Candidates for advanced degrees are considered who have undergraduate or graduate work in any area of civil engineering, in operations research and industrial engineering, and in economics. Students with other backgrounds and well-developed career objectives will also be considered for graduate studies.

GEOTECHNICAL ENGINEERING

Mr. D. J. Henkel, Chairman; Messrs. D. J. Belcher, M. I. Esrig, W. L. Hewitt, T. Liang, G. B. Lyon, A. J. McNair. Visiting Staff: B. LeLievre.

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 are 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. G. Winter, Chairman; Messrs. S. J. Errera, R. H. Gallagher, P. Gergely, W. McGuire, A. H. Nilson, R. G. Sexsmith, F. O. Slate, and R. N. White.

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., aero-space 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. Visiting Staff: G. Terzidis.

Water resources engineering brings together undergraduate instruction, advanced study and research in fluid mechanics, hydraulics, hydrology, sanitary (environmental) engineering and water resource systems engineering. Departmental activities fall into three general categories: (1) the development of fundamental knowledge of pertinent phenomena and principles through theoretical analysis and laboratory experimentation; (2) the application of these principles, along with skills in applied mathematics, statistics and probability, and digital computation techniques, to the analysis and design of processes and systems for water quality control, water quantity control, and waste management; (3) the application of mathematical modeling, economic theory, and systems analysis to the solution of problems in water resource planning and management, and in environmental quality control.

Undergraduates may concentrate in this subject area either by choosing the Field Program in Civil Engineering and electing advanced courses offered by the Department or by electing the *College Program* and choosing an engineering major within the Department. Individuals considering graduate study in this area should have a baccalaureate degree in engineering science, a branch of engineering, or in 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 *Announcement of the Graduate School: Physical Sciences.* A brochure, *Graduate Study in Civil Engineering,* may be obtained by writing the Graduate Field Representative, Civil Engineering, Hollister Hall.

THE COLLEGE PROGRAM

DEGREES OFFERED: Bachelor of Science.

CARPENTER HALL

Mr. W. H. Erickson, Chairman, College Program Committee.

The *College Program* has been established to accommodate those students whose educational objectives require more curricular flexibility than is possible in the Field Programs. Thus, to reach a given objective, a student in the *College Program* may combine course sequences from two or more engineering fields or combine an engineering course sequence with a sequence from a nonengineering discipline. Many combinations are possible under the Program as established, and the College Program Committee, which administers the Program, approves all proposals that combine sequences of courses that have an educational objective requiring an engineering foundation.

Similar to the Field Programs in that the same core curriculum requirements must be satisfied, the *College Program* differs from them in that the courses to satisfy the forty to forty-six additional credit hours are not specified by the engineering faculty, but are to be suggested by the student when he applies for admission to the *College Program.* Such admission is normally at the beginning of the student's junior year but applications are made in the first term of the sophomore year.

Within these forty to forty-six credit hours, the student is required to have a minimum of twelve hours in an engineering major, eight hours in an engineering minor, and eight hours in technical electives, with the remaining hours to be satisfied by courses appropriate to the student's objective. The engineering minor may be waived if the objective of the student is best satisfied by a combination of an engineering major and a minor that is in a nonengineering discipline.

Completion of the application form for admission to the Program requires a statement of the objective of the student and a term-by-term listing of the courses that are proposed for meeting this objective. It is not expected that the student will compile such a listing on his own, but that, after discussing his objective with the chairman of the *College Program* Committee, he will develop his program with the advice of a technical consultant in the field of the proposed major. The technical consultant will be a professor recommended to the student by the chairman of the Committee.

Once admitted to the Program, the student's progress is under the supervision of the *College Program* Committee. His adviser is the chairman of the Committee. The Committee is responsible for all the administrative functions normally performed by the faculty of a Field Program. Examples of student programs currently in progress are:

Major	*Minor*
Airphoto Interpretation	Geology
Transportation	Regional planning
Computer science	Electrical systems
Electrical systems	Psychology
Electrical systems	Biological science
Industrial engineering	Psychology
Nuclear engineering	Engineering physics
Materials science	Geology
Machine design	Electrical systems
Thermal engineering	Industrial engineering
Theoretical and applied mechanics	Applied mathematics
Environmental systems	Industrial engineering
Mechanical engineering	Oceanography
Environmental systems	City planning
Water resources	Thermal engineering
Electrical systems	Premedical
Computer science	Industrial engineering

After completing the *College Program* the student is awarded a Bachelor of Science degree. In planning his *College Program,* the student should consider his graduate objective whether it be Master of Science, Doctor of Philosophy, or Master of Engineering, and should so construct his program that he has the proper prerequisites for the graduate work he contemplates.

COMPUTER SCIENCE

(COLLEGES OF ENGINEERING AND OF ARTS AND SCIENCES)

DEGREES OFFERED: Master of Science; Doctor of Philosophy.

UPSON HALL

Mr. J. Hartmanis, Chairman; Messrs. K. M. Brown, R. L. Constable, R. W. Conway, J. E. Hopcroft, W. L. Maxwell, H. L. Morgan, C. Pottle, G. Salton, A. C. Shaw, R. A. Sweet, R. A. Wagner, R. J. Walker, P. Wegner, W. S. Worley.

Computer science, the science of information, is concerned with the nature and properties of information, its structures and classification, its storage and retrieval, and the various types of processing to which it can be subjected. It is also concerned with the physical machines that perform these operations, with the elemental units of which they are composed, and with the organization of these units into efficient information processing systems.

Computer science is closely related to many other fields. The fundamental theory of information processing and the exploration of the limits of the abilities of computing machines are topics in pure and applied mathematics. Numerical analysis, which is concerned with the accuracy and efficiency of practical numerical procedures, is a topic in applied mathematics. Computer science and electrical engineering have a common interest in the characteristics of physical machines and in computer design. Linguistics and computer science share an interest in language structure and translation. The implications of current data processing technology for the organization and control of industrial and business operations are pertinent to industrial engineering and business administration. Investigations in the area of artificial intelligence are subjects of interest in psychology and biology. Work in experimental computing relates to several of the disciplines already mentioned.

In the past, many of these subjects were pursued as parts of separate fields. Today greater stress is placed on their common basis, and computer or information science is being established as an independent discipline at many leading institutions. Because research in this field is related to the work of so many disciplines, the Department of Computer Science at Cornell is organized as an intercollege department of the College of Engineering and the College of Arts and Sciences.

Computing Facilities

The principal computing facility at Cornell is an IBM 360 Model 65. This is located in Langmuir Laboratory at the Cornell Research Park on the periphery of the campus, and is directly linked to satellite computors at three different campus locations. The Engineering College 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

In the Field of Computer Science, qualified graduate students can earn Master of Science and Doctor of Philosophy degrees. Although there is no undergraduate field program in computer science in the College of Engineering, it is possible for students in the *College Program* (described on p. 53) to develop a course of study which emphasizes computer science and related fields.

Because of the importance of a strong background in mathematics and engineering sciences, undergraduates in the *College Program* who are interested in advanced study in computer science should plan a course of upperclass study that will include work in applied mathematics, probability and statistics, and electrical engineering, as well as appropriate courses in computer science.

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 typically 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 two foreign languages (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, or the M.S. followed by the Ph.D.

ELECTRICAL ENGINEERING

DEGREES OFFERED: Bachelor of Science; Master of Engineering (Electrical); Master of Science; Doctor of Philosophy.

PHILLIPS HALL

Mr. H. J. Carlin, Director; Mr. J. L. Rosson, Assistant Director; Messrs. P. D. Ankrum, J. M. Ballantyne, T. Berger, R. Bolgiano, N. M. Brice, N. H. Bryant, R. E. Curry, G. C. Dalman, L. F. Eastman, W. H. Erickson, D. T. Farley, T. L. Fine, T. Gold, B. Hoefflinger, C. E. Ingalls, F. Jelinek, M. Kim, C. A. Lee, R. L. Liboff, S. Linke, L. A. MacKenzie, H. S. McGaughan, P. R. McIsaac, C. A. Merriam III, J. A. Nation, B. Nichols, R. E. Osborn, E. Ott, C. Pottle, N. J. A. Sloane, H. G. Smith, R. N. Sudan, G. Szentirmai, C. L. Tang, J. S. Thorp, H. C. Torng, N. M. Vrana, L. S. Wagner, C. B. Wharton, G. J. Wolga, S. W. Zimmerman. Visiting Staff: Mr. B. J. Leon.

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 enables the student to follow one of three possible routes to advanced studies. They are:

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 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 page 62 for a general description of these 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 and computer-aided design; microwave propagation; radio physics; and solid state microwave devices. 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, and plasmas. In the curriculum, these subjects are treated in significant depth and breadth. All undergraduate students enrolled in the E.E. 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, as well as the response of these systems to various inputs. These systems may be solely electrical or involve transducers; they may contain both linear and nonlinear elements; they may be passive, active, or random. Systems may be used for many purposes, e.g., power distribution control, communications, and instrumentation. The course program is designed to develop the general methods of analysis required for all such systems together with understanding of the physical significance of the solutions. All undergraduate students enrolled in the E.E. 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 brings students into close touch with reality in the areas of both systems and electrophysics. The experimental work may be based on the analysis developed in either of the areas. 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 E.E. Field Program are required to complete 4321, 4322, and six additional hours of E.E. 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 housed 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, switching circuits, microwave electronics, physical and solid state electronics, quantum electronics including high power lasers, plasma and gas discharge phenomena, and high energy pulse power. The Arecibo Ionospheric Observatory at Arecibo, Puerto Rico, has 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)

		Contact Hours	
TERM 5	*Credit Hours*	*Lec. Rec.*	*Lab. Comp.*
Engineering 4301, Analysis of Electrical Systems I	4	3	2½
Engineering 4311, Electromagnetic Fields and Waves	4	3	2½
Engineering 4321, Electrical Laboratory I	4	1	5
Engineering 3631, Thermodynamics*	3	3	–
Liberal Elective*	3	–	–
Total	18		

TERM 6			
Engineering 4302, Analysis of Electrical Systems II	4	3	2½
Engineering 4312, Electromagnetic Fields and Waves	4	3	2½
Engineering 4322, Electrical Laboratory II	4	[illegible]	5
Engineering 3632, Fluid Mechanics*	3	3	–
Liberal Elective*	3	[illegible]	–
Total	18		

TERM 7

	Credit Hours	Contact Hours Lec. Rec.	Contact Hours Lab. Comp.
Engineering 4401, Deterministic Signals in Linear Systems	4	3	2½
Engineering 4411, Quantum Theory and Applications†	4	3	2½
E. E. Elective with laboratory	3 or 4	1 or 2	2½ to 5
Liberal Elective*	3	–	–
Free Elective	3	–	–
Total	17 or 18		

TERM 8

	Credit Hours	Contact Hours Lec. Rec.	Contact Hours Lab. Comp.
Engineering 4402, Random Signals in Linear Systems	4	3	2½
Engineering 4412, Solid State Physics and Applications†	4	3	2½
E. E. Elective with laboratory	3 or 4	1 or 2	2½ to 5
Liberal Elective*	3	–	–
Free Elective	3	–	–
Total	17 or 18		

* The engineering science and liberal electives listed above are part of the core curriculum requirements described on page 11.

† 4411 and 4412 satisfy the core curriculum engineering science requirements of physical chemistry and materials science.

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. It is hoped that students will use these elective courses to pursue effectively their individual interests in the Field Program of Electrical Engineering.

THEORY OF SYSTEMS AND NETWORKS

4501 Systems with Random Signals and Noise
4502 Statistical Aspects of Communication
4503 Theory of Linear Systems I
4504 Theory of Nonlinear Systems I
4507–08 Random Processes in Electrical Systems
4571 Network Analysis
4572 Network Synthesis
4601 Theory of Nonlinear Systems II
4603 Theory of Linear Systems II

ELECTROMAGNETIC THEORY

4511 Electrodynamics
4514 Microwave Theory
4567 Antennas and Radiation
4568 Advanced Antenna Methods and Problems

LABORATORY

4421–22 Advanced Electrical Laboratory
4520 Graduate Laboratory

ELECTRONICS

4431–32 Electronic Circuit Design
4433–34 Semiconductor Electronics I and II
4531–32 Quantum Electronics I and II
4535–36 Solid State Devices I and II
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
4562 Waves in Plasmas
4564 Advanced Plasma Physics
4565–66 Radiowave Propagation I and II
4661 Kinetic Equations

COMMUNICATIONS

4472 Introduction to Algebraic Coding
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
4505–06 Optimization and Approximation Techniques I and II
4588 Bionics and Robots
4681 Random Processes in Control Systems

MASTER OF ENGINEERING (ELECTRICAL)

Admission to the Master of Engineering (Electrical) degree program is open to persons who have been granted Bachelor's degrees, or the equivalent, and who have sufficient training to indicate 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 are:

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, two-course sequences 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.

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 receiving 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, 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. Assistantship applications and further information can be obtained by writing to the Graduate Field Representative, School of Electrical Engineering, Phillips Hall.

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 39).

CLARK HALL

Mr. T. R. Cuykendall, Director; Messrs. B. W. Batterman, K. B. Cady, D. D. Clark, R. K. Clayton, D. R. Corson, E. T. Cranch, H. H. Fleischmann, P. L. Hartman, J. A. Krumhansl, R. McPherson, M. S. Nelkin, H. F. Newhall, E. L. Resler, Jr., T. N. Rhodin, N. Rostoker, and H. S. Sack, Mrs. M. M. Salpeter; Messrs. B. M. Siegel, J. Silcox, W. W. Webb, G. J. Wolga. Visiting Staff: Mr. I. Kuščer.

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, encourages this approach among students with an interest and competence for such areas. It seeks to prepare students for the continually widening engineering challenges with deepening roots in fundamental knowledge which are produced by physical research.

The student pursues thorough and advanced courses in physics and applied mathematics. He is encouraged to develop insight into the application of concepts. To this end, his curriculum includes a core of engineering sciences and a systematic development of electrical and electronic systems. Thus he may proceed from a basic understanding of matter and energy through a knowledge of techniques to a number of applied themes. By selecting electives, he opens for himself the way to several modern technological areas such as recent advances in gasdynamics, aerodynamics, plasmas, 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 in 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 principal activities of the School take place in Clark Hall, which also houses the Department of Physics, and in the Nuclear Reactor Laboratory. Clark Hall is the center for undergraduate affairs such as student records, scheduling, and advising. Graduate activities and projects related to the Master of Engineering (Engineering Physics) degree are carried out in both buildings.

Equipment is available for project 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.

Five commercial electron microscopes are used in research activities. Ultrahigh resolution instruments for atomic and molecular microscopy are being developed. Superconducting and magnetic phenomena are being studied at very low temperatures. Apparatus and equipment for studying nuclear engineering and related nuclear phenomena are extensive. (See page 89).

The Degree Programs

Of the core engineering sciences that may be completed before the end of the fourth semester in the Division of Basic Studies, the physical chemistry-materials science sequence and electrical science sequence are required. Familiarity with the phenomena occurring in materials and in electrical systems provides a good basis for building deeper and wider understanding as well as sound applications. The relationship between interest and proficiency in physics and mathematics at this and later stages of progress is obvious.

While students may enroll in the engineering physics program from the nonhonors section of physics and mathematics, registration in honors sections is very desirable and strongly recommended.

Initiation of the study of a specialty is encouraged through courses such as Physics 444, Nuclear and High-Energy Particle Physics; or Engineering 8309, Low Energy Nuclear Physics; Physics 454, Introductory Solid State Physics; and additional topics in Physics 410, Advanced Experimental Physics.

By suitable selection of technical electives during his last year, or through studies for the Master of Engineering (Engineering Physics) degree, the qualified student may prepare for a career in one of the many specialized fields of engineering. As examples, six possible programs are outlined:

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.

AEROSPACE ENGINEERING (see page 31). 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 in physics of solids underlying radiation damage problems. His attention is directed to courses 8303, 8309, 8312, 8351, and to 5760, 6873, and 7201. Additional 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, 8212), materials science and engineering, and specialized seminars provides 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, photoconductivity, and others.

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 gas-dynamics, 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 pages 27–29).

		Contact Hours	
TERM 5	*Credit Hours*	*Lec. Rec.*	*Lab. Comp.*
Math 421, Applicable Mathematics	4	4	0
Physics 355, Intermediate Electrodynamics	3	3	0
Engineering 8133, Mechanics of Particles and Solid Bodies	3	3	0
Engineering 4301, Analysis of Electrical Systems I	4	3	1
Engineering 4921, Electrical Engineering Laboratory	1	0	1
Liberal Elective	3 or 4		
Total	18 or 19		

TERM 6

	Contact Hours		
	Credit Hours	Lec. Rec.	Lab. Comp.
Math 422, Applicable Mathematics	4	4	0
Physics 356, Intermediate Electrodynamics	3	3	0
Engineering 8134, Mechanics of Continua	3	3	0
Engineering 4302, Analysis of Electrical Systems II	4	3	1
Engineering 4922, Electrical Engineering Laboratory	1	0	1
Liberal Elective	3 or 4	–	
Total	18 or 19		

TERM 7

Mathematics 423, Applicable Mathematics	4	4	0
Physics 443, Atomics and Introductory Quantum Mechanics	3	3	0
Engineering 8121, Thermodynamics and Fluid Mechanics	3	3	0
Free Elective	3	–	–
Liberal Elective	3 or 4	–	–
Total	16 or 17		

TERM 8

Physics 444, Nuclear and High-Energy Particle Physics	4	4	0
or			
Physics 454, Introductory Solid State Physics			
or			
Engineering 8309, Low Energy Nuclear Physics	3	0	0
Physics 410, Advanced Experimental Physics	4	1	6
Engineering 8122, Statistical Mechanics and Kinetic Theory	3	3	0
Free Elective	3	0	0
Liberal Elective	3 or 4	0	0
Total	16 to 18		

THE COLLEGE PROGRAM

The *College Program* (see page 53), 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 are:

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

Physics 355, Intermediate Electrodynamics
Physics 356, 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 Department.

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, prosecuting 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 guide lines 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, either 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 who is active in the subject.

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 by the Curriculum Committee of the Department.

3. Physics 572, Quantum Mechanics.

4. A minimum of six hours in an engineering course sequence.

5. Chemistry 596, or an equivalent course to be arranged with adviser's approval.

6. A seminar course—a modified version of 8252. One credit hour or more by arrangement.

7. Technical electives to bring the total credit hours to thirty.

MASTER OF ENGINEERING (NUCLEAR)

This program is described elsewhere in the *Announcement*. See page 88.

ENVIRONMENTAL SYSTEMS ENGINEERING

(see page 51.)

GEOTECHNICAL ENGINEERING

(see page 52.)

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 page 91).

UPSON HALL

Mr. B. W. Saunders, Director; Messrs. R. N. Allen, R. E. Bechhofer, R. H. Bernhard, H. Emmons, H. P. Goode, K. O. Kortanek, W. L. Maxwell, N. U. Prabhu, M. Rubinovitch, S. Saltzman, M. W. Sampson, A. Schultz, Jr., H. M. Taylor III, 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, as well as 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 not only industrial systems but also 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 queueing 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 five years 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. degree or a 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 page 56). 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 pages 27–29 of this *Announcement*. The Division of Basic Studies program specifies two engineering science courses in each term of the sophomore year. For industrial engineering students, these can be any two that are offered, with the mechanics and the physical chemistry-materials science sequences preferred. The remaining two will then be scheduled during the junior year in order to delay electives until the senior year when a wider choice will be available because of the student's more complete preparatioin at that point.

		Contact Hours	
TERM 5	*Credit Hours*	*Lec. Rec.*	*Lab. Comp.*
Engineering Science*	3	–	–
Engineering 9301, Introduction to Industrial Engineering	3	2	2
Engineering 9381, Introduction to Computer Science	4	2	2½
Engineering 9360, Introduction to Probability Theory with Engineering Applications	4	3	2½
Liberal Elective	3	3	–
Total	17		

TERM 6			
Engineering Science*	3	–	–
Engineering 3632, Fluid Mechanics	3	3	–
Engineering 9350, Cost Accounting, Analysis, and Control	4	3	2½
Engineering 9370, Introduction to Statistical Theory with Engineering Applications	4	3	2½
Liberal Elective	3	3	–
Total	17		

* This will be the third engineering science course mentioned above (under the heading "Bachelor of Science") and not taken in the second year. It will generally be Electrical Engineering 4941–4942.

Note: Students may take four-credit hour elective courses in place of three-credit hour courses where they so desire.

TERM 7

	Credit Hours	Contact Hours Lec. Rec.	Lab. Comp.
Engineering 9310, Industrial Engineering Analysis	4	3	2½
Engineering 9320, Deterministic Models in I.E. and O.R.	4	3	2½
Technical Elective	4	–	–
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	18		

TERM 8

	Credit Hours	Contact Hours Lec. Rec.	Lab. Comp.
Engineering 9303, Industrial Engineering Laboratory	4	2	5
Engineering 9321, Probabilistic Models in I.E. and O.R.	4	2	5
Technical Elective	4	–	–
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	18		

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 C, or who is not otherwise making substantial and steady progress toward the completion of his degree, may be suspended.

Elective Courses

The industrial engineering curriculum is designed to provide considerable flexibility in its elective content. A liberal elective, chosen from the offerings of the College of Arts and Sciences in either the humanities or the social sciences, must be taken each term of the third and fourth years. This will allow some depth in these subjects which should be chosen to complement the required science and engineering courses. In the fourth year, eight hours of technical electives and six hours of free electives offer the student innumerable opportunities to develop programs to meet his special needs and objectives. Work can be taken in parallel engineering fields to provide greater breadth for an engineering career before specialization is started in the fifth year.

If the student has decided to go on to a teaching or research career and to pursue the advanced research degrees, more mathematics can be elected. If he has decided to continue for the Master of Engineering degree, the fourth-year electives should be planned to enhance that program and combine with those electives available in the M.Eng. program. If he has decided to apply the industrial engineering training to another professional field such as City and Regional Planning or Business and Public Administration, some electives can be devoted to the introductory work in those fields. It is important, therefore, that the elective program be carefully planned and that frequent consultation with the Director and/or the student's adviser be managed so as to take advantage of the flexibility provided in the curriculum.

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 to the design of new or improved man-machine systems, informations systems, and control systems.

Applications will also be accepted 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.

		Contact Hours	
	Credit	*Lec.*	*Lab.*
FALL TERM	*Hours*	*Rec.*	*Comp.*
Engineering 9526, Mathematical Models—Development and Application	4	3	2½
Engineering 9580, Digital Systems Simulation	4	3	–
Engineering 9593, Industrial Engineering Graduate Seminar	1	1½	–
Engineering 9598, Project	2	As Arranged	
Professional Elective	3	–	–
Total	14		
SPRING TERM			
Engineering 9521, Production Planning and Control	4	3	–
Engineering 9551, Advanced Engineering Economic Analysis	4	3	–
Engineering 9594, Industrial Engineering Graduate Seminar	1	1½	–
Engineering 9599, Project	4	As Arranged	
Professional Elective	3	–	–
Total	16		

MACHINE DESIGN AND MATERIALS PROCESSING

(See page 83.)

MATERIALS SCIENCE AND ENGINEERING

DEGREES OFFERED: Bachelor of Science; Master of Engineering (Materials); Master of Science; Doctor of Philosophy.

BARD HALL

Mr. W. S. Owen, Director; Mr. M. S. Burton, Assistant Director; Messrs. R. W. Balluffi, B. W. Batterman, J. M. Blakely, P. S. Ho, J. O. Jeffrey, H. H. Johnson, E. J. Kramer, C. Y. Li, A. L. Ruoff, S. L. Sass, E. Scala, D. N. Seidman, S. V. Smith, A. Taylor. Visiting Staff: Mr. H. B. Huntington.

Materials science relates the principles of physics and chemistry to materials. Modern engineering requires new and improved materials having properties not attainable a few years ago. Thus, further understanding of the nature of materials and control of their properties has become essential. Empirical approaches have been replaced by theoretical and analytical treatments of the relationships between the physical properties and the structure of metallic and nonmetallic solids from the macroscopic to the atomic scale. Selection, processing, and application of materials for specific needs is materials engineering.

Laboratory and Research Facilities

The Materials Science and Engineering Department is centered in Bard Hall, occupying, in addition, parts of Thurston Hall and Kimball Hall, a total area of 50,000 square feet. Facilities include the newest of the Cornell engineering buildings, Bard Hall, completed in 1963, and 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 established at Cornell with funds from the Advanced Research Projects Agency. The Materials Science Center supports central facilities in Bard, Thurston, and Clark Halls for service and research in metallography, x ray diffraction, electron microscopy, effects of high temperature on materials and effects of 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 curricula provide 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. These include discussions of crystallographic and other structural aspects, mechanical behavior, phase transformations and kinetics, and electrical and magnetic properties of materials. Through suitable choice of electives there can be considerable program flexibility.

There are *two* general course programs: the *materials science* program emphasizes the scientific basis of the subject; the *materials science and engineering* program contains required courses in chemical and mechanical materials processing in place of some of the courses in mathematics and solid state physics which are required in the Materials Science Program.

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 pages 27–29.

Materials Science Program

		Contact Hours	
	Credit	*Lec.*	*Lab.*
TERM 5	*Hours*	*Rec.*	*Comp.*
Engineering 6031, Structure of Materials I	3	3	0
Engineering 6033, Structure of Materials II	2	2	0
Engineering 6035, Thermodynamics and Fluid Mechanics	3	3	0
Physics 355, Intermediate Electrodynamics	3	3	0
Engineering 1150, Advanced Engineering Analysis I	3	3	0
Liberal Elective	3–4*	–	–

	Credit Hours	Contact Hours Lec. Rec.	Contact Hours Lab. Comp.
TERM 6			
Engineering 6032, Mechanical Properties of Materials	3	3	0
Engineering 6034, Structure of Materials Laboratory	3	0	4½
Engineering 6036, Thermodynamics of Condensed Systems	3	3	0
Physics 360, Introductory Electronics	3	2	2½
Engineering 1151, Advanced Engineering Analysis II	3	3	0
Liberal Elective	3–4*	–	–
TERM 7			
Engineering 6041, Kinetics	3	3	0
Engineering 6043, Senior Materials Laboratory I	3–4†	0	5
Physics 443, Atomics and Introductory Quantum Mechanics	4	4	0
Liberal Elective	3–4*	–	–
Free Elective	3–4‡	–	–
TERM 8			
Engineering 6042, Electrical and Magnetic Properties	3	3	0
Engineering 6044, Senior Materials Laboratory II	3–4†	0	5
Physics 454, Introductory Solid State Physics	4	4	0
Liberal Elective	3–4*	–	–
Free Elective	3–4‡	–	–

* Minimum for B.S. degree is 133 credits. Students must take in excess of the minimum during some terms to meet this requirement.

† Students will normally register for three credits, but may register for four credits with the consent of the instructor.

‡ Students intending to take a professional engineering degree in materials science are advised to elect the materials processing courses, Engineering 6045, 6046.

Materials Science and Engineering Program

	Credit Hours	Contact Hours Lec. Rec.	Contact Hours Lab. Comp.
TERM 5			
Engineering 6031, Structure of Materials I	3	3	0
Engineering 6033, Structure of Materials II	2	2	0
Engineering 6035, Thermodynamics and Fluid Mechanics	3	3	0
Engineering 241, Electrical Science,‡ or Engineering 4941, Introductory Electrical Engr.	3	3	0
Free Elective	3	–	–
Liberal Elective	3–4*	–	–
TERM 6			
Engineering 6032, Mechanical Properties of Materials	3	3	0
Engineering 6034, Structure of Materials Laboratory	3	0	4½
Engineering 6036, Thermodynamics of Condensed Systems	3	3	0
Engineering 242, Electrical Science,‡ or Engineering 4942, Introductory Electrical Engr.	3	3	0
Free Elective	3	–	–
Liberal Elective	3–4*	–	–
TERM 7			
Engineering 6041, Kinetics	3	3	0
Engineering 6043, Senior Materials Laboratory I	3–4†	0	5
Engineering 6045, Materials Processing I (Mechanical)	3	3	0
Free Elective	3	–	–
Liberal Elective	3–4*	–	–

	Contact Hours		
	Credit Hours	Lec. Rec.	Lab. Comp.
TERM 8			
Engineering 6042, Electrical and Magnetic Properties	3	3	0
Engineering 6044, Senior Materials Laboratory II	3–4†	0	5
Engineering 6046, Materials Processing II (Chemical)	3	3	0
Free Elective	3	–	–
Liberal Elective	3–4*	–	–

* Minimum for B.S. degree is 133 credits. Students must take in excess of the minimum during some terms to meet this requirement.

† Students will normally register for three credits, but may register for four credits with the consent of the instructor.

‡ Students who complete Engineering 241, 242 as sophomores will register for Engineering 211, 212.

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 to plan a suitable program and to select appropriate elective courses.

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

Chemistry 357, Introductory Organic Chemistry
Chemistry 358, Introductory Organic Chemistry
Chemistry 410, Inorganic Chemistry
Chemistry 481, Advanced Physical Chemistry
Engineering 1159, Experimental Mechanics
Engineering 1163, Applied Elasticity
Engineering 1168, Theory of Plasticity
Engineering 3331, Kinematics and Components of Machines
Engineering 3372, Experimental Methods in Machine Design
Engineering 3665, Transport Processes
Engineering 5742, Polymeric Materials
Engineering 5752, Polymeric Materials Laboratory
Engineering 5760, Nuclear and Reactor Engineering
Engineering 6762, Physics of Solid Surfaces
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. All students will be required to take Materials Science 6210, 6211. Additional courses in materials science or materials engineering will complete the major or minor sequence. These will be selected to meet the needs of each student: (See pages 53–55 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 but 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 courses of study and research 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 and he may then proceed directly to the Ph.D. without taking the M.S.

The courses offered by the Field presume 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.

MECHANICAL ENGINEERING

DEGREES OFFERED: Bachelor of Science; Master of Engineering (Mechanical); Master of Science; Doctor of Philosophy.

UPSON HALL

Mr. D. G. Shepherd, Director; Messrs. N. W. Abrahams, 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, S. Leibovich, H. N. McManus, Jr., F. K. Moore, R. M. Phelan, K. E. Torrance, R. L. Wehe. Visiting Staff: Mr. B. K. Gupta.

Mechanical engineering is the broadest of the several 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: *Machine Design and Material Processing* (see p. 83), and *Thermal Engineering* (see p. 83). 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 introduce the student to the complete design of a mechanical engineering system. For those completing the five years of study culminating in the Master of Engineering (Mechanical) degree, this objective of integrated design is extended to include the opportunity to understake a design project requiring considerable individual study.

The liberal course electives prescribed in the core program are scheduled one each term in the third and fourth years, with the two unrestricted electives available in the fourth year. In addition, the program allows for two technical electives in the fourth year. *Technical elective* means any course in engineering, science, or mathematics which contributes to the particular educational objective of the student. This elective program allows each student to pursue an option in his undergraduate work, whether it be directed toward a particular branch of technology or as preparation for advanced 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 which broadens 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 breadth of training in mechanical engineering leads to several possibilities for advanced study following the B.S. degree. If possible, the student should plan his route to advanced work in his third year so that full advantage may be made of the total of four technical and unrestricted electives available in the fourth year. 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 (see paragraph 2) or not changing their field for advanced work (see paragraph 3). Details of this program are given on 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.

Machine Design and Materials Processing

Mr. H. N. McManus, Jr., Chairman; Messrs. J. F. Booker, A. H. Burr, G. B. DuBois, R. L. Geer, B. K. Gupta, A. I. Krauter, S. Oldberg, R. M. Phelan, R. L. Wehe.

The Department of Machine Design and Materials Processing is responsible for those aspects of mechanical engineering involving the analysis and design of machines, their components and systems. It is also concerned with the related field of manufacturing, particularly with material removal methods. It supports class and individual design projects. Its graduate students and staff engage in these projects or in research activities to obtain performance characteristics and design data for machines and to obtain physical phenomena in related mechanical sciences. The current interests of its staff include conceptual design methods, electro-mechanical controls, automatic control systems, mechanical vibration studies, and bearing performance and lubrication theory.

The Department has its own laboratories for stress, photoelastic, vibration, and endurance testing of machine parts as well as for the study of hydraulic and pneumatic controls. Numerous electronic instruments are available for the measurement and recording of force, motion, strain, vibration, and noise. The laboratories are particularly well equipped for studies of lubrication phenomena in journal bearings and for studies requiring the use of analog computers.

The materials processing laboratories, with a generous selection of production-type machine tools, provide undergraduate and research facilities for tool planning, statistical quality control, surface texture, and dynamometric projects. Specially tooled and instrumented equipment for studying tool wear and geometry characteristics, chip formation, work-tool temperature phenomena, and stress patterns is available. For metrology and gaging studies, a constant temperature room is available. The laboratories are well equipped with all standard-type measuring devices, including optical, electronic, and pneumatic comparators.

Thermal Engineering

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

Thermal engineering is concerned with those aspects of mechanical engineering involving the production, transfer, and utilization of energy. The particular areas of interest include thermodynamics, heat transfer, fluid flow, and reacting systems. These subject areas are of both theoretical and practical interest.

The laboratories of the Department are well equipped for undergraduate instruction and for the support of graduate research. Current research interests of the staff members include high temperature and nonequilibrium effects in fluid dynamics; plasma processes; heat transfer in the convective, conductive, radiative and combined modes; and areas of statistical, irreversible, and classical thermodynamics. Concern with real systems is a feature of the research.

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 139.

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 pages 27–29). In the sophomore year, two engineering science sequences are required. Students desiring to pursue a program in mechanical engineering must take the *mechanics* sequence, since it is a prerequisite for junior courses; *materials science* is recommended for the second sequence, but is not required.

In the junior and senior years, fifty-four credit hours of technical courses related to mechanical engineering are required. These include courses in the Mechanical Engineering Departments of Thermal Engineering and of Machine Design and Materials Processing, plus specified courses in industrial engineering and operations research and in materials science and engineering. In addition, eighteen credit hours in liberal and unrestricted electives are required. *Unrestricted electives* may be any courses in the University to which the student can gain admission, including six hours of advanced ROTC.

To be in good standing in the School of Mechanical Engineering, a student must, each term, earn a passing grade in at least fifteen credit hours, with a grade of C minus or better in eleven hours. If he fails in any term to pass twelve hours, he may be suspended from the School. No undergraduate student may take fewer than fifteen credit hours per term.

BACHELOR OF SCIENCE

TERMS 1–4

See Division of Basic Studies Curriculum (pp. 27–29).

TERM 5	Credit Hours	Lec. Rec. (Contact Hours)	Lab. Comp. (Contact Hours)
Engineering Science (Electrical or Materials)	3	2	2½
Engineering 3321, Kinematics and Dynamics of Mechanisms	3	2	2½
Engineering 3431, Materials Processing	3	1	5
or			
Engineering 9170, Introductory Engineering Statistics	3	2	2½
Engineering 3621, Introduction to Thermodynamics	3	3	0
Engineering 6316, Materials Engineering	3	2	2½
Liberal Elective*	3 or 4	–	–
Total	18 or 19		

TERM 6	Credit Hours	Lec. Rec. (Contact Hours)	Lab. Comp. (Contact Hours)
Engineering Science (Electrical or Materials)	3	2	2½
Engineering 3322, Analysis and Design of Machine Components	3	2	2½
Engineering 3622, Engineering Thermodynamics	2	2	0
Engineering 3623, Fluid Mechanics	4	4	0
Engineering 9170, Introductory Engineering Statistics	3	2	2½
or			
Engineering 3431, Materials Processing	3	1	5
Liberal Elective*	3 or 4	–	–
Total	18 or 19		

TERM 7	Credit Hours	Lec. Rec. (Contact Hours)	Lab. Comp. (Contact Hours)
Engineering 3053, Mechanical Engineering Laboratory	4	1	5
Engineering 3324, Vibration and Control of Mechanical Systems	3	2	2½
Engineering 3625, Heat Transfer	3	3	0
Liberal Elective*	3 or 4	–	–
Unrestricted Elective	3	–	–
Technical Elective	3	–	–
Total	19 or 20		

* See page 30 for definition of liberal electives.

	Credit Hours	Contact Hours Lec. Rec.	Lab. Comp.
TERM 8			
Engineering 3054, Design of Mechanical Engineering Systems	4	2	5
Engineering 3626, Thermal Systems Engineering	4	2	2½
Liberal Elective*	3 or 4	–	–
Unrestricted Elective	3	–	–
Technical Elective	3	–	–
Total	17 or 18		

* See page 30 for definition of liberal electives.

MASTER OF ENGINEERING (MECHANICAL)

This degree is available as a curricular type of professional degree, the general requirements for which are stated on page 00. 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 3651, Advanced Thermal Science	3
Engineering Laboratory* or Mechanical Engineering Elective	3
Technical Elective	3
Total	15

SPRING TERM	Credit Hours
Mathematics	3
Engineering 3055, Advanced Mechanical Engineering Design	3
Engineering 3090, Mechanical Engineering Design Project	3
Mechanical Engineering Elective or Engineering Laboratory*	3
Technical Elective	3
Total	15
Total for two terms	30

* 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); Advanced Flow Measurement, 3673 (fall); or Techniques of Thermal Measurement, 3667 (spring). 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, 3090, in the spring term, provides design experience requiring individual effort and the preparation of a formal report. 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 the Chairman, Graduate Professional Engineering Program, 221 Carpenter Hall. Further information on the program can be obtained from the Director, School of Mechanical Engineering, 105 Upson Hall.

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 such as heat transfer, fluid mechanics, energy conversion, plasma studies, lubrication, mechanical systems dynamics, stress analysis and machine tools. 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 Field Representative, Sibley School of Mechanical Engineering, Upson Hall.

NUCLEAR SCIENCE AND ENGINEERING

DEGREES OFFERED: Master of Engineering (Nuclear); Master of Science; Doctor of Philosophy.

NUCLEAR REACTOR LABORATORY

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, S. Linke, R. McPherson, M. Nelkin, R. L. Von Berg. Visiting Staff: Mr. I. Kuščer.

Faculty of the *Graduate Field* of Nuclear Science and Engineering, supervising the M.S. and Ph.D. 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 treats 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 as well as from engineering physics.

Laboratory and Research Facilities

The Nuclear Reactor Laboratory 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 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 Cockroft-Walton accelerator for studies of radiation effects and low energy nuclear levels and reactions; (4) a shielded cell with 10,000 curies of Co^{60} gamma sources for radiation chemistry studies; (5) a radiochemistry laboratory; and (6) subcritical assemblies for reactor physics investigations.

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

Physics 436, Modern Physics
Engineering 8351, Nuclear Measurements Laboratory
Engineering 5760, Nuclear and Reactor Engineering
Engineering 6873, Materials Science for Engineers (same as Engineering 8337)

MINOR IN NUCLEAR ENGINEERING

Physics 436, Modern Physics
Engineering 8303, Introduction to Nuclear Science and Engineering
Engineering 8351, Nuclear Measurements Laboratory
or
Engineering 6873, Materials Science for Engineers (same as Engineering 8337)

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 its 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 are:

Engineering 8334, Nuclear Engineering Seminar
Physics 444, Nuclear and High-Energy Particle Physics
Engineering 5505, Advanced Heat Transfer
Engineering 7201–7202, Magnetohydrodynamics I and II
Engineering 1163, Applied Elasticity
Engineering 3665, Transport Processes
Engineering 3672, Energy Conversion

Master of Science and Doctor of Philosophy

A candidate for either research 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 are the following:

Mathematics 415–416, Mathematical Methods in Physics
Physics 561, Theoretical Physics I
Physics 572, Quantum Mechanics
Engineering 8309, Low Energy Nuclear Physics
Engineering 8312, Nuclear Reactor Theory
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, radio-chemistry, radiation chemistry, activation analysis, and radiation detection. Areas of research in nuclear engineering include neutral particle transport theory, reactor statics and dynamics, nuclear materials and fuels, basic processes in the production and use of power from nuclear reactions, and selected problems in nuclear reactor design and optimization.

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 Graduate Field Representative, Nuclear Reactor Laboratory.

OPERATIONS RESEARCH

DEGREES OFFERED: Master of Science; Doctor of Philosophy.

UPSON HALL

Mr. R. E. Bechhofer, Chairman; Messrs. R. H. Bernhard, L. J. Billera, M. Brown, R. W. Conway; Mrs. S. C. Dafermos; Messrs. H. Emmons, H. P. Goode, J. C. Kiefer, K. O. Kortanek, W. R. Lynn, W. L. Maxwell, H. L. Morgan, N. U. Prabhu, M. Rubinovitch, S. Saltzman, B. W. Saunders, A. Schultz, Jr., S. Stidham, Jr., H. M. Taylor III, L. I. Weiss. Visiting Staff: Mr. M. F. Neuts.

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 are among the major techniques employed. Optimization techniques such as mathematical programming (linear, nonlinear, and probabilistic), combinatorics, and dynamic programming are also used extensively.

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, however, may range from making a fundamental contribution to the techniques of operations research to applying operations research to problems in diverse professional areas.

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, 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 in government. Research activity may involve the developing of new methodology or the synthesizing of new combinations from what is already known. Such activity can improve the understanding of systems or can lead to the development of new decision criteria for such 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 with 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), control systems engineering (Electrical Engineering), econometrics (Economics), managerial economics (Business and Public Administration), mathematics (Mathematics), regional planning (City and Regional Planning), and water resources (Water Resources). Students who are interested in minoring in any of these subjects should refer to the respective Field programs listed elsewhere in this *Announcement.*

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 been 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 about any of the graduate programs may be obtained by writing to the Graduate Field Representative of Operations Research, Upson Hall.

STRUCTURAL ENGINEERING

(see page 52.)

THEORETICAL AND APPLIED MECHANICS

DEGREES OFFERED: Master of Science; Doctor of Philosophy.

THURSTON HALL

Mr. E. T. Cranch, Chairman; Messrs. K. T. Alfriend, H. D. Block, B. A. Boley, H. D. Conway, C. M. Dafermos, M. D. Greenberg, R. H. Lance, G. S. S. Ludford, J. R. Moynihan, Y. H. Pao, R. H. Rand, D. N. Robinson. Visiting Staff: Mr. S. A. Thau.

The Department of Theoretical and Applied Mechanics is responsible for undergraduate and graduate instruction and research in theoretical and applied mechanics and applied mathematics. 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 major and minor individualized, planned programs in a newly initiated *College Program*.

The graduate program in mechanics and applied mathematics emphasizes fundamental understanding of the newest developments in engineering and applied science. Graduate students are exposed to the mechanics of liquids, gases, particles, rigid and deformable solids, and related areas of materials, mathematics, and physics. The analytical nature of the studies encourages research that cuts across various fields.

Graduate students may pursue programs in the following areas of specialization: (1) space mechanics—including research on trajectories and orbits of space vehicles and satellites as well as the theory of lightweight, thin-walled structures; (2) wave propagation in solids—with research on the waves in layered media, scattering of elastic waves and dynamic stress concentrations, waves in plates, rods and shells; (3) structural mechanics including static and dynamic loading, vibrations, and buckling; (4) theory of elasticity and plasticity; (5) theoretical fluid mechanics—with research in gas dynamics 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, *Graduate Study in Theoretical and Applied Mechanics* can be obtained by writing the Graduate Field Representative, Theoretical and Applied Mechanics, Thurston Hall.

The College Program

Faculty members of the Department are prepared to sponsor individual undergraduate students desiring a program in engineering science as a *College Program* (see page 53). The course details of such a program will be dependent upon the educational goal of the student and will be worked out in consultation with a member of the Department, but all such programs will have the following general form:

TERM 5

Engineering Science (core requirement)
Thermodynamics
Math or Engineering Analysis
Electrical Science, Physics, or Engineering Science
Liberal Elective

TERM 6

Engineering Science (core requirement)
Fluid Mechanics
Math or Engineering Analysis
Electrical Science, Physics, or Engineering Science
Liberal Elective

TERM 7

Electrical Science, Physics, or Engineering Science
Math or Engineering Analysis
Advanced Dynamics
Liberal Elective
Free Elective

TERM 8

Electrical Science, Physics, or Engineering Science
Math or Engineering Analysis
Continuum Mechanics
Liberal Elective
Free Elective

Students wishing to pursue Engineering Science as a *College Program* should discuss the matter with the Department Chairman.

THERMAL ENGINEERING

(see page 83.)

WATER RESOURCES ENGINEERING

(see page 53.)

DESCRIPTION OF COURSES

Course descriptions are listed under the school, department, or division in which they are offered. Certain English, 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, and 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. The first digit(s) 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	Machine Design and Materials Processing (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
	AGRICULTURAL ENGINEERING
	BASIC STUDIES
	COMPUTER SCIENCE

BASIC STUDIES DIVISION

Engineering Problems and Methods

103. ENGINEERING GRAPHICS AND DESIGN (u)

Credit 3 hrs. Either term. 1 Lect., 1 Rec., 1 Lab. Fundamentals of the engineering graphic language including orthographic drawing and sketching, pictorial drawing and sketching, auxiliaries, sections, intersections, and developments. Instrument drawings will show applications of visual communication in the design process. Freehand conceptual design. Mr. W. L. Hewitt.

104. INTRODUCTION TO ENGINEERING (u)

Credit 3 hrs. Either term. 2 Lect., 1 Lab. Orientation to the engineering profession: discussion of curriculum, engineering functions, engineering fields, introduction to technical report writing. Digital computing: machine language, problems, and computer applications. Engineering design: analysis of factors such as safety, reliability, efficiency, and economy that contribute to sound design. Mr. W. H. Erickson.

Mathematics

191. CALCULUS FOR ENGINEERS (u)

Credit 4 hrs. Either term. 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. 9, Oct. 30, Nov. 20, Dec. 11. Plane analytic geometry, differential and integral calculus, applications.

193. CALCULUS FOR ENGINEERS (u)

Credit 4 hrs. Fall. 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. 9, Oct. 30, Nov. 20, Dec. 11. Plane analytic geometry, differential and integral calculus, applications.

192. CALCULUS FOR ENGINEERS (u)

Credit 4 hrs. Either term. 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. 19, Mar. 12, Apr. 9, May 7. Spring term. Transcendental functions, technique of integration and multiple integrals, vector calculus, analytic geometry in space, partial differentiation, applications.

194. CALCULUS FOR ENGINEERS (u)

Credit 4 hrs. Spring. 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. 19, Mar. 12, Apr. 9, May 7. Covers contents of Course 192 in more detail and includes more theoretical material.

293–293H. ENGINEERING MATHEMATICS (u)

Credit 4 hrs. Either term. 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. Preliminary examinations will be held at 7:30 P.M. on Oct. 15, Nov. 12, Dec. 10. 293H is an honors section of 293 in fall term only. Vectors and matrices, first-order differential equations, infinite series, complex numbers, applications. Problems for programming and running on the automatic computer will be assigned, and students are expected to have a knowledge of computer programming equivalent to that taught in Engineering 104.

294–294H. ENGINEERING MATHEMATICS (u)
Credit 3 hrs. Either term. Prerequisite, 293. Fall term: M W F 8, 12:20. Spring term: lectures, M W 8, 12:20 plus recitation periods to be arranged. Preliminary examinations will be held at 7:30 P.M. on Mar. 4, Mar. 25, May 6. 294H is an honors section of 294 in spring term only. Linear differential equations, quadratic forms and eigenvalues, differential vector calculus, applications.

Physics

121–122. INTRODUCTORY ANALYTICAL PHYSICS I AND II (u)
Credit 3 hrs. a term. Throughout the year. (Physics 121 is also offered in the spring term, T Th S 9:05, for those students who have completed but failed the course in the preceding fall term; permission of the instructor is required.) Prerequisite, calculus or coregistration in Mathematics 191–192, or consent of the instructor. Course 121 is prerequisite to 122. Primarily for students of engineering. Lecture, F 9:05 or 11:15 or 1:25. Two 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. 8, Nov. 12, Dec. 10, Mar. 4, Apr. 15, and May 6. The mechanics of particles: kinematics, dynamics, conservation of energy, conservation of linear momentum, circular motion, special relativity. Rotation of rigid bodies. Harmonic motion. The properties of the fundamental forces: gravitational, electromagnetic, and nuclear. At the level of *Introductory Analytical Physics,* fourth edition, by Newhall. Messrs. Newhall, Chester, Horwitz, Krumhansl, McDaniel, and staff.

233–234. INTRODUCTORY ANALYTICAL PHYSICS III AND IV (u)
Credit 3 hrs. a term. Throughout the year. (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 or 1:25. Two discussion periods every week, as assigned. Each term the course is subdivided into three independent sections, each of no more than 180 students (and for each lecture, no more than ninety students). Preliminary examinations will be held at 7:30 P.M. on Oct. 11, Nov. 8, Dec. 13, Feb. 20, Mar. 20, and April 24. 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. Fall term, Messrs. Orear, Rostoker, Silverman, and Shepherd. Spring term, Messrs. Edwards, Groom, and Littauer.

235–236. LABORATORY TO ACCOMPANY PHYSICS 233–234 (u)

Credit 1 hr. a term. Throughout the year. Must be taken with Physics 233–234. Course 235 is prerequisite to 236. One two-hour period every week, as assigned. Experiments include electrical measurements, circuits, physical electronics, optics, lasers, atomic spectroscopy, solid state, nuclear and particle physics. Messrs. Lee, Loh, Richardson, and staff.

237–238. INTRODUCTORY ANALYTICAL PHYSICS III AND IV (u)

Credit 4 hrs. a term. Throughout the year. 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 or Th 2–4:25. Topics include those (none omitted) in Physics 233–234 but their treatment is generally more analytical and somewhat more intensive. At the level of *Lectures on Physics,* Vol. II, 1964, by Feynman, of *Spacetime Physics,* 1966, by Taylor and Wheeler, and of *Fundamentals of Optics and Modern Physics,* 1968, by Young. Fall term, Mr. Berkelman and staff. Spring term, Mr. Delvaille and staff.

Chemistry

107–108. GENERAL CHEMISTRY (u)

Credit 3 hrs. fall term and 4 hrs. spring term. Throughout the year. Prerequisite, high school chemistry; 104 or 107 are prerequisites to 108. Enrollment is limited. Recommended for those students who will take further courses in chemistry. Lectures, T Th 9:05 and 10:10. Laboratory, W F or S 8–11; T or Th 1:25–4:25; M W or F 1:25–4:25. Scheduled preliminary examinations may be held in the evening. The important chemical principles and facts are covered, with considerable attention given to the quantitative aspects and to the techniques that are important for further work in chemistry. Second-term laboratory includes a systematic study of qualitative analysis. Fall term, Mr. Freed; spring term, Mr. Fay; and assistants.

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

287–288. INTRODUCTORY PHYSICAL CHEMISTRY (u)

Credit 3 hrs. a term. Throughout the year. Prerequisites, Chemistry 108 or 116 and Mathematics 111–112 or consent of the instructor. Chemistry 287 is prerequisite to 288. Lectures, M W F 9:05. Preliminary examinations may be given in the evening. A systematic treatment of the fundamental principles of physical chemistry. Mr. Albrecht and assistants.

289–290. INTRODUCTORY PHYSICAL CHEMISTRY LABORATORY (u)

Credit 2 hrs. a term. Throughout the year. Coregistration in Chemistry 287–288 required. Chemistry 289 is prerequisite to 290. Laboratory lecture, F 12:20. Laboratory, M T or W Th 1:25–4:25 or F 1:25–4:25, S 8–11. The development of needed skills in the experimental aspects concerned with the fundamental principles of physical chemistry.

Engineering Sciences

241–242. ELECTRICAL SCIENCE I AND II (u)

Credit 3 hrs. Throughout the year. 3 Lect.-Rec. Prerequisites, Mathematics 192 and Physics 122 and coregistration in Mathematics 293 and Physics 223. An integrated sequence providing an introduction to modern electrical engineering. Simple models are developed for a wide variety of electrical devices. and interactions between several devices are considered. Analytical and graphical techniques for calculating responses to various excitations of simple electrical systems containing these devices are included. Indicative of the types of systems considered are: networks of linear resistances and capacitances subjected to steady and sinusoidal excitations; circuits contriode and transistor amplifiers; inductive systems, both linear and nonlinear, such as transformers and elementary electromechanical transducers; and simple distributed systems such as transmission line and resonators. Throughout the sequence, emphasis is placed upon the physical principles underlying system behavior.

211. MECHANICS OF RIGID AND DEFORMABLE BODIES I (u)

Credit 4 hrs. Fall and spring. 2 Lect., 1 Rec., 1 (2-hour) Comp.-Lab. Prerequisites, coregistration in Mathematics 293 and Physics 233. Force systems and equilibrium. Distributed forces, static friction, statically determinate plane structures. Concepts of stress and strain. Shearing force, bending moment, bending and tension of beams. Analysis of plane stress and strain, combined stress, thermal stress. Theories of failure. Instability of columns. (Evening prelims.)

212. MECHANICS OF RIGID AND DEFORMABLE BODIES II (u)

Credit 4 hrs. Spring and summer. 2 Lect., 1 Rec., 1 (2-hour) Comp.-Lab. Prerequisite, Mechanics 211. Inelastic behavior. Energy methods in mechanics. Principles of particle dynamics. Theory of oscillations. Kinematics of rigid body motion. Dynamics of systems of particles. Kinetics of rigid bodies. (Evening prelims.)

6210–6211. MATERIALS SCIENCE (u)

Credit 3 hrs. 6210 offered fall and spring. 6211 offered spring and summer. Prerequisites, Mathematics 192, Chemistry 108. 2 Lect.; 1 Lab., 1 Rec., alternate weeks. An introduction to the basic concepts of materials science. (1) Structure. Structure of gases, liquids and solids, atomic binding, observations of structure by x-ray diffraction, packing concepts and crystalline defects, microstructures.

(2) Thermodynamics and Equilibrium. Laws of thermodynamics; chemical and physical reactions; phase equilibria, electrochemical systems, thermodynamical and statistical mechanical models of solutions, equilibrium defects, surfaces.

(3) Kinetics. Reaction rates in gases and condensed systems; atomic and ionic transport processes; kinetics of phase transformation.

(4) Properties. Mechanical, electrical and magnetic properties of materials with emphasis on structure-sensitive properties. Messrs. Blakely and Ruoff.

5101. MASS AND ENERGY BALANCES (Chemical Engineering) (u)

Credit 3 hrs. Fall. 3 Lect., 1 Comp. period. Parallel, Physical Chemistry 287, 289. Engineering problems involving material and energy balances. Flow-sheet systems and balances. Total energy balances for flow systems. Mr. Thorpe.

5102. EQUILIBRIA AND STAGED OPERATIONS (Chemical Engineering) (u)

Credit 3 hrs. Spring. 3 Lect., 1 Comp. period. Parallel, Physical Chemistry 288, 290. Phase equilibria and phase diagrams. The equilibrium stage, mathematical description of single and multistage operations, analytical and graphical solutions. Mr. Thorpe.

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

7101. ADVANCED KINETIC THEORY (g)

Credit 3 hrs. Fall. The Boltzmann equation. Solution for gas in equilibrium. Collision frequency and mean free path calculations. Conservation equations. Review of Enskog-Chapman theory of transport coefficients. Grad's thirteen moment equations. The BGK equation. The BBGKY theory. Mr. de Boer.

7102. GASDYNAMICS (g)

Credit 3 hrs. Spring. 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. Mr. Resler.

7103. DYNAMICS OF RAREFIED GASES (g)

Credit 3 hrs. Spring. Prerequisite, 7101. 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. Mr. Shen.

7104. ADVANCED TOPICS IN HIGH TEMPERATURE GASDYNAMICS (g)

Credit 3 hrs. Either term. Prerequisites, 7101, 7102. Current topics relating to present engineering practice and/or research interests of the faculty and staff. Staff.

7201. INTRODUCTORY PLASMADYNAMICS (g)

Credit 3 hrs. Fall. Macroscopic and microscopic properties of plasmas. Wave motion and stability. Character of laboratory-produced and naturally occurring plasma systems. Application to power conversion and space propulsion. Introduction to controlled thermonuclear research. Mr. Auer.

7202. INTRODUCTORY MAGNETOHYDRODYNAMICS (g)

Credit 3 hrs. Spring. Basic equations of magnetohydrodynamics. Flow problems. Hydromagnetic shock waves. The pinch effect and instabilities. Tensor conductivity and excess electron temperature. Mr. Turcotte.

7203. INTERMEDIATE PLASMA PHYSICS (g)

Credit 3 hrs. Spring. Prerequisite, 4561 or 7201 or equivalent. Collective oscillations in a cold plasma; waves in a warm plasma; application to natural phenomena. Non-linear 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,* Stix; and *Radiation Processes in Plasmas,* Bekefi.) Mr. Auer.

7301. FLUID MECHANICS (g)

Credit 3 hrs. Fall. The continuum and the stress tensor. Vectors and tensors. Hydrostatics. Strain and rate-of-strain tensors. Constitutive equations. The ideal elastic continuum. Equilibrium and compatibility equations, boundary conditions. Plane stress and strain. The stress function. Elastic energy. Venant's principle. 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. Irrotational flows. Mr. George.

7302. AERODYNAMICS (g)

Credit 3 hrs. Spring. Laplace's equation. Source, sink, and doublet. Vortices. Boit-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. Mr. Sears.

7303. COMPRESSIBLE FLUID FLOW (g)

Credit 3 hrs. Spring. 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. Mr. George or Mr. Seebass.

7304. THEORY OF VISCOUS FLOWS (g)

Credit 3 hrs. Fall. 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. Mr. Shen.

7305. HYPERSONIC FLOW THEORY (g)

Credit 3 hrs. On demand. Prerequisites, 7301, 7302. 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. Mr. George or Mr. Seebass.

7801. RESEARCH IN AEROSPACE ENGINEERING (g)

(Credit to be arranged.) 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 1 hr. 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 2 hrs. 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. Staff.

7903. PLASMA PHYSICS COLLOQUIUM (g)

Credit 1 hr. Fall and spring. 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)

Credit 3 hrs. Spring. 1 Lect., 2 Lab. A study of the principles and methods of engineering measurements. Fundamentals of measurement, sources of errors, and measurement systems will be considered, with emphasis upon surveying measurements. Special attention will be given to methods for obtaining measurements that are required in a variety of agricultural engineering problems. CUPL, the Cornell computing language, will be taught and used in the solution of these problems. Mr. Rehkugler.

153. ENGINEERING DRAWING (u)

Credit 3 hrs. Fall. 2 Lect., 1 Lab. 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 of the laboratory will be utilized as an instruction-recitation period. Mr. Longhouse.

450. SPECIAL TOPICS IN AGRICULTURAL ENGINEERING (u)

Credit 1 hr. Spring. Open only to seniors. Presentation and discussion of the opportunities, qualifications, and responsibilities for positions of service in the various fields of agricultural engineering. Mr. French.

461. AGRICULTURAL MACHINERY DESIGN (u,g)

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisite, Engineering 3331 or the equivalent. 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. Mr. Gunkel.

[462. AGRICULTURAL POWER (u,g)]

Credit 3 hrs. Fall. 2 Lect., 1 Lab. and computing periods. Prerequisite, Engineering 212, or the equivalent. 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. Not given in 1968–69.

463. PROCESSING AND HANDLING SYSTEMS FOR AGRICULTURAL MATERIALS (u,g)

Credit 4 hrs. Spring. 3 Lect., 1 Lab. Processes such as size reduction, separation metering, drying, and refrigeration will be studied. Psychrometrics, fluid flow measurement, and an introduction to systems engineering and electrical controls for agricultural applications are included. Mr. Furry.

[471. SOIL AND WATER ENGINEERING (u,g)]

Credit 3 hrs. Spring. 3 Lect., 1 Lab. every other week. Prerequisites, Engineering 3632 and Agronomy 200, or their equivalents. 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. Not given in 1968–69.

[481. AGRICULTURAL STRUCTURES (u,g)]

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisites, Engineering 2701 and 3621. 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. Not given in 1968–69.

491. LOW-COST ROADS (u,g)

Credit 3 hrs. Primarily for applications to developing countries. Offered upon sufficient demand, usually in fall term. Prerequisite, consent of instructor. Principally directed study with one 2½-hour class session per week. 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. Mr. Spencer.

501. SIMILITUDE ENGINEERING (g)

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Similitude methodology, including the use of dimensional analysis to develop general equations to define physical phenomena; model theory; distorted models; and analogies, including the use of electronic analog and digital computers. Introduction to a variety of applications in engineering. It is preferred that students know how to program in Fortran, although knowledge of CUPL is acceptable. Mr. Furry.

502. INSTRUMENTATION (g)

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisite, permission of instructor. Application of instrumentation to physical and biological measurements in agricultural and biological research, including measurement of force, displacement, velocity, acceleration, pressure flow of materials, electric and magnetic quantities, temperature, humidity, chemical composition analysis, particle size, and electric magnetic radiation with emphasis on transducers and recording methods. Mr. Scott.

504. BIOLOGICAL ENGINEERING ANALYSIS (g)

Credit 3 hrs. Fall. 3 Lect. Prerequisite, consent of instructor, or Engineering 1151. 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. Mr. Cooke.

505. SOLID WASTE MANAGEMENT (u,g)

Credit 3 hrs. Spring. Prerequisite, permission of instructor. Study of municipal, industrial and agricultural solid wastes. Emphasis on waste characteristics, method of treatment, and disposal and interelationship with air, water and land environment. Discussion of economic and political aspects. Intended primarily for graduate students but open to qualified undergraduates. Mr. Loehr.

551–552. AGRICULTURAL ENGINEERING PROJECT (g)

Total credit 6 hrs. (Required for M.Eng. degree) 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. Staff.

600. SPECIAL TOPICS (g)

Credit 1 or more hrs. Fall or spring. Special work in any area of agricultural engineering on problems of special interest to the students and faculty.

601. GENERAL SEMINAR (g)

Fall and spring. Fall term required of all graduate students majoring in Field. Spring term, optional.

602. POWER AND MACHINERY SEMINAR (g)

603. SOILS AND WATER ENGINEERING SEMINAR (g)

604. AGRICULTURAL STRUCTURES SEMINAR (g)

Seminars 602, 603, 604. Credit 1 hr. Spring. Thorough investigation and discussion of research or new developments in an area of special interest to those enrolled.

APPLIED PHYSICS

8051 and 8052. PROJECT (g)

Credit 3 hrs. Fall and spring. 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)

Fall or spring. Laboratory or theoretical work in any branch of engineering physics under the direction of a member of the staff. Hours to be arranged.

8121. THERMODYNAMICS AND FLUID MECHANICS (u)

Credit 3 hrs. Fall. 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. Mr. Resler.

8122. STATISTICAL MECHANICS AND KINETIC THEORY (u)

Credit 3 hrs. Spring. Prerequisite, 8121 or equivalent. 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 F-Reif, *Fundamentals of Statistical and Thermal Physics.* Mr. Webb.

8133. MECHANICS OF PARTICLES AND SOLID BODIES (u)

Credit 3 hrs. Fall. 3 Rec. Primarily for majors in engineering physics. Newton's laws, harmonic oscillator, Fourier series and Green's function solutions, Lagrange equations, Hamiltonian formalism, central force motion, orbits, scattering, cross-sections. Many particle dynamics, Lagrangian formulation. Lorentz transformation. Mr. Rhodin.

8134. MECHANICS OF CONTINUA (u)

Credit 3 hrs. Spring. 3 Rec. Primarily for majors in engineering physics. Mechanics of continua, equilibrium, propagation of sound waves. Elasticity, torsion, shear, bending stresses. Mr. Fleischmann.

8205. ELECTRICAL AND MAGNETIC PROPERTIES OF ENGINEERING MATERIALS (g)

Credit 3 hrs. Fall. (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 Kittel, *Introduction to Solid State Physics;* Chikazumi, *Physics of Magnetism;* Lynton, *Superconductivity;* Livingston and Schadler, *The Effect of Metallurgical Variables on Superconductivity Properties.* Mr. Webb.

8211. PRINCIPLES OF DIFFRACTION (g)

Credit 3 hrs. Fall. Offered jointly with the Department of Materials Science and Engineering. 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)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 8211. Offered jointly with the Department of Materials Science and Engineering. 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)

Credit 1 hr. Fall. 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.

8262. PHYSICS OF SOLID SURFACES (g)

Credit 3 hrs. Spring. A lecture course for graduate students and upperclassmen offered jointly with the Department of Materials Science and Engineering. (6762). 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,* Editors, Seitz and Turnbull.

8303. INTRODUCTION TO NUCLEAR SCIENCE AND ENGINEERING (u,g)

Credit 3 hrs. Fall. 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. Messrs. Cady and McPherson.

8309. LOW ENERGY NUCLEAR PHYSICS (g)

Credit 4 hrs. Spring. 3 Lect. Prerequisite, an introductory course in atomic and nuclear physics including quantum mechanics. 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. Mr. McPherson.

8312. NUCLEAR REACTOR THEORY I (g)

Credit 4 hrs. Fall. 3 Lect. Prerequisites, one year of advanced calculus and an introductory course in atomic and nuclear physics. The physical processes in neutron chain reactors are described. The theory of neutron diffusion and slowing down is developed and applied to those processes. Neutron transport theory is introduced at the level of *Nuclear Reactor Theory* by Lamarsh.

8313. NUCLEAR REACTOR THEORY II (g)

Credit 3 hrs. Spring. 3 Lect. 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. Mr. Cady.

8314. NEUTRON TRANSPORT THEORY (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 8312 or consent of instructor. 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. Mr. Kuščer.

8333. NUCLEAR REACTOR ENGINEERING (g)

Credit 4 hrs. Fall. 3 Lect. Prerequisite, consent of instructor. 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. Mr. Cady.

8334. NUCLEAR ENGINEERING DESIGN SEMINAR (g)

Credit 4 hrs. Spring. Prerequisite, 8333. A conceptual design study of a nuclear reactor system. Emphasis on the interplay of requirements of safety and economics in the design of nuclear power systems. Mr. Cady.

8337. MATERIALS SCIENCE FOR ENGINEERS (see Materials Science 6873) (g)

Credit 3 hrs. Fall.

8351. NUCLEAR MEASUREMENTS LABORATORY (g)

Credit 4 hrs. Either term. Two 2½-hour afternoon periods. Prerequisite, some knowledge of nuclear physics. Laboratory experiments plus lectures on interaction of radiation with matter and on radiation detection, including electronic circuits. Some twenty different experiments are available in the fields of nuclear and reactor physics. Among these are experiments on emission and absorption of radiation; on radiation detectors and nuclear electronic circuits; on interactions of neutrons with matter (absorption, scattering, moderation, and diffusion); on activation analysis and radiochemistry; and on 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 laid on independent work by the student. Mr. McPherson.

8352. ADVANCED NUCLEAR AND REACTOR LABORATORY (g)

Credit 3 hrs. Either term. Two 2½-hour afternoon periods. Prerequisites, 8351 and 8309 or 8312. Laboratory experiments plus lectures on experimental methods in nuclear physics and reactor physics. Some ten different experiments are available, among them ones using the Zero Power Reactor critical facility.

8601. PHYSICAL APPROACHES TO PROBLEMS OF PHOTOSYNTHESIS (u,g)

Credit 3 hrs. Fall. (Same as Bio. Sci. 545) Given in alternate years. Prerequisites, Chemistry 104 or 108, Mathematics 112, Physics 208, or by permission of the instructor. Lectures M 1:25, T Th 10:10. 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,* R. K. Clayton (Blaisdell Publishing Co., Waltham, 1965). Mr. Clayton.

[8603. GENERAL PHOTOBIOLOGY (u,g)]

Credit 3 hrs. Fall. (Same as Bio. Sci. 547) Given in alternate years. Prerequisites same as for Bio. Sci. 545. Lectures M 1:25, T Th 10:10. 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. Not offered 1968–69.

CHEMICAL ENGINEERING

5041. NONRESIDENT LECTURES (g)

Fall. 1 Lect. 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. Mr. Winding.

5101. MASS AND ENERGY BALANCES (u)

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Parallel, Physical Chemistry 287. Engineering problems involving material and energy balances. Flow-sheet systems and balances. Total energy balances and flow systems. Mr. Thorpe.

5102. EQUILIBRIA AND STAGED OPERATIONS (u)

Credit 3 hrs. Spring. 2 Lect., 1 Comp. Parallel, Physical Chemistry 288. Phase equilibria and phase diagrams. The equilibrium stage; mathematical description of single and multistage operations; analytical and graphical solutions. Mr. Thorpe.

5103. CHEMICAL ENGINEERING THERMODYNAMICS (u)

Credit 3 hrs. Spring. 3 Lect. Prerequisites, Chemistry 287, 288. A study of the first and second laws with application to batch and flow processes. Physical and thermodynamic properties. Availability; free energy; chemical equilibrium. Application to gas compression; process steam; power generation; adiabatic reactors; and chemical process development. Mr. Von Berg.

[5105. ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS (g)]

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 5104 or equivalent. Application of the general thermodynamics method to advanced problems in chemical engineering. Evaluation, estimation and correlation of properties. Chemical and phase equilibria. Not offered 1968–69.

5106. REACTION KINETICS AND REACTOR DESIGN (g)

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 5304. A study of chemical reaction kinetics and principles of reactor design for chemical processes. Mr. Finn.

5107. ADVANCED REACTION KINETICS (g)

Credit 3 hrs. Fall. 3 Lect. 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. Mr. Harriott.

5108. COLLOIDAL AND SURFACE PHENOMENA (g)

Credit 3 hrs. Fall. Prerequisite, physical chemistry. 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. Mr. Finn.

5161. PHASE EQUILIBRIA (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, physical chemistry. 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. Mr. Thorpe.

5203. CHEMICAL PROCESSES (u)

Credit 4 hrs. Spring. 4 Lect. An analysis of important chemical processes and industries. Mr. Wiegandt.

5205. CHEMICAL PROCESS SEMINAR (g)

Credit 2 hrs. Fall. For graduate students. A discussion of recent advances in chemical process development. Mr. Wiegandt.

5256. MATERIALS (u)

Credit 4 hrs. Spring. 4 Lect. Prerequisites, 5101, 5102, Chem. 287, 288. 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. Mr. Cocks.

5303. ANALYSIS OF STAGE PROCESSES (u)

Credit 3 hrs. Fall. 3 Lect., 1 Comp. Prerequisites, 5101, 5102. An analysis of separations involving mass transfer in stage processes. Design variables, prediction of equilibrium and non-ideal solutions, binary, multicomponent, and extractive distillation, liquid-liquid extraction. Extensive use made of digital computer. Desirable to have some knowledge of CUPL, the Cornell Computing Language. Messrs. Leinroth and Watt.

5304. INTRODUCTION TO RATE PROCESSES (u)

Credit 3 hrs. Spring. 2 Lect., 1 Comp. Prerequisite, 5303. An introduction to fluid mechanics, heat and mass transfer. Mr. Scheele.

5312. SPECIALIZED UNIT OPERATIONS (g)

Credit 3 hrs. Fall. 3 Lect. 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. Mr. Edwards.

5353. UNIT OPERATIONS LABORATORY (u)

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisite, 5304. Laboratory experiments in fluid dynamics, heat transfer, and mass transfer. Correlation and interpretation of data. Technical report writing. Messrs. Cocks, Edwards, Harriott, and Winding.

5354. PROJECT LABORATORY (u)

Credit 3 hrs. Spring. Prerequisite, 5353. Special laboratory projects involving bench-scale or pilot-plant equipment. Messrs. Leinroth and Watt.

5505, 5506. ADVANCED TRANSPORT PHENOMENA (g)

Credit 4 hrs. each term. Fall and spring. 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. Messrs. Harriott, Smith, and Scheele.

5605, 5606, 5607, 5608. DESIGN PROJECT (g)

Credit variable. Fall and spring. 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, etc. Staff.

5609. ANALYSIS AND DESIGN OF PROCESS EQUIPMENT (g)

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 5304 or consent of instructor. Discussion and analysis of operating principles, design, and selection of chemical process equipment. Mr. Smith.

5621. PROCESS DESIGN AND ECONOMICS (g)

Credit 6 hrs. Fall. Prerequisites, 5104, 5204, 5304. Methods for estimating capital and operating costs. Performances, selection, design, and cost of process equipment. Process development and design. Market research and survey. Mr. York.

5622. PROCESS AND PLANT DESIGN (g)

Credit 6 hrs. Spring. Prerequisite, 5621. Continuation of 5621. 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. Mr. York.

[5635. MARKETING OF CHEMICAL PRODUCTS (g)]

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 5621. Examination of marketing activities, organizations, and costs in the distribution of chemicals. Chemical prices. A market research project is required. Alternate years. Not offered in 1968–69.

5636. ECONOMICS OF THE CHEMICAL ENTERPRISE (g)

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 5621. Research economics; feasibility studies; information services; venture analysis; depreciation and amortization; planning. Mr. Hedrick.

[5641. INVENTIONS, PATENTS, AND TRADE SECRETS (g)]

Credit 3 hrs. Fall. Prerequisite, or parallel, 5621. 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. Not offered 1968–69.

[5642. DEVELOPMENT ECONOMICS (g)]

Credit 3 hrs. Spring. Prerequisites, 5621, 5622, 5641. Planning, evaluation, and management of development activities in the process industries, as related to research, processing, new products, markets, and long-range growth. Not offered 1968–69.

5717. PROCESS CONTROL (g)

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisite, 5304. 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. Mr. Harriott.

5741. PETROLEUM REFINING (g)

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 5304. A critical analysis of the processes employed in petroleum refining. Mr. Wiegandt.

5742. POLYMERIC MATERIALS (u)

Credit 3 hrs. Fall. 3 Lect. Chemistry and physics of the formation and characterization of polymers. The engineering applications of polymers as plastics, fibers, rubbers, and coatings. Mr. Rodriguez.

5743. PROPERTIES OF POLYMERIC MATERIALS (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 5742. Phenomenological aspects and molecular theories of non-Newtonian flow, viscoelasticity, and ultimate tensile properties. Special topics. Mr. Rodriguez.

[5745. ANALYSIS OF POLYMERIC PROCESSES (g)]

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 5256 or 5742. 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. Not offered 1968–69.

5746. CASE STUDIES IN THE COMMERCIAL DEVELOPMENT OF CHEMICAL PRODUCTS (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, or parallel, 5622. 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. Mr. Hedrick.

5748. FERMENTATION ENGINEERING (g)

Credit 3 hrs. Spring. 2 Lect., 1 Rec. 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)

Credit 1 hr. Fall. 1 Lect. Prerequisites, organic chemistry and physical chemistry. A brief introductory course in microbiology for students with a good background in chemistry. Mr. Finn.

5752. POLYMERIC MATERIALS LABORATORY (g)

Credit 2 hrs. Fall. 1 Lab. Prerequisite, 5256 or 5742. Experiments in the formation, characterization, fabrication, and testing of polymers. Mr. Rodriguez.

5760. NUCLEAR AND REACTOR ENGINEERING (g)

Credit 2 hrs. Fall. 2 Lect. Prerequisite, 8302 or consent of the instructor. Fuel processing and isotope separation, radioactive waste disposal, fuel cycles, radiation damage, biological effects and hazards, shielding, power reactors. Mr. Von Berg.

5790. CONSUMER PRODUCTS ENGINEERING (same as Industrial Engineering and Operations Research 9514) (u,g)

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Open to qualified seniors and graduate students in engineering. 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 product industries is stressed. Staff will be from industry.

5851. CHEMICAL MICROSCOPY (u)

Credit 3 hrs. Either term. 1 Lect., 2 Lab. Prerequisites, or parallel courses, Chemistry 287, 288, or 387, 388 and Physics 223, 224 or special permission. Microscopical examination of chemical and technical materials, processes and products. Measurement, particle size determination, analyses of mixtures, crystallization, phase changes and colloidal phenomena. Mr. Cocks.

5857. ELECTRON MICROSCOPY (g)

Credit 2 hrs. Fall. 1 Lect., 1 Lab. Prerequisite, Chemical Microscopy 5851 or special permission. An introduction to the principles of electron microscope, including: electron optics, the operation and care of the microscope, methods of specimen preparation, and the interpretation of electron microscopical images. Mr. Cocks.

5859. ADVANCED CHEMICAL MICROSCOPY (g)

Offered on demand either term. Credit variable. Prerequisite, 5851 and special permission. Laboratory practice in special methods and special applications of chemical microscopy. Mr. Cocks.

5900. SEMINAR (g)

Credit 1 hr. Fall and spring. General chemical engineering seminar required of all graduate students majoring in the field of chemical engineering. Staff.

5903. SEMINAR IN BIOCHEMICAL ENGINEERING (g)

Credit 1 hr. Spring. Advanced topics in the engineering applications of biophysics and biochemistry. Discussion of current research in the field. Staff.

5909. RESEARCH SEMINAR (g)

Fall. 1 Lect. Required of all students enrolled in the predoctoral honors program. An introduction to the research methods and techniques of chemical engineering. Staff.

5952, 5953, 5954. RESEARCH PROJECT (g)

Credit 3 hrs.; additional credit by special permission. Fall and Spring. Prerequisite, 5304. Research on an original problem in chemical engineering.

5955, 5956. SPECIAL PROJECTS IN CHEMICAL ENGINEERING (g)

Credit variable. Either term. 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)

Credit 3 hrs. On demand. Prerequisite, fourth year or graduate standing. 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 will be used extensively.

2010. CIVIL ENGINEERING DESIGN PROJECT I (g)

Credit 2 hrs. Fall. Normally required for students in the M.Eng. (Civil) program. 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)

Credit 3 hrs. Spring. Prerequisite, 2010. Normally required for students in the M.Eng. (Civil) program. Continuation of 2010.

Environmental Systems Engineering

201. MICROECONOMIC ANALYSIS (u)

Credit 3 hrs. Fall. Lectures, M W F 10:10. Prerequisite, one year of college level mathematics. Topics include the theory of the firm, of production, of market structures, of consumer behavior, and of welfare economics. May not be taken for credit in addition to Econ. 103.

202. MACROECONOMIC ANALYSIS (u)

Credit 3 hrs. Spring. Lecture, M W F 10:10. Prerequisite, 201. 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. 104.

301. MICROECONOMIC ANALYSIS (g)

Credit 3 hrs. Fall. This course is an introduction to microeconomic analysis for graduate students. It offers the same lectures as 201 but has an additional discussion section and a more intensive reading list.

302. MACROECONOMIC ANALYSIS (g)

Credit 3 hrs. Spring. This course is an introduction to macroeconomic analysis for graduate students. It offers the same lectures as 202 but has an additional discussion section and a more intensive reading list.

2601. TRANSPORTATION ENGINEERING (u,g)

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Transportation systems analysis; traffic generation, distribution, and assignment models; modal split models. Elements of traffic flow theory and congestion. Physical environment evaluation, including route location and use of aerial photography. Transport economics. Technological and economic characteristics of current transportation modes. Current policy issues. Laboratory includes subgrade and pavement design, signalization methods and devices, geometric design and drainage. Under special circumstances, may be scheduled as lectures only for 2 hrs. credit.

2602. LAW FOR ENGINEERS (u,g)

Credit 3 hrs. Fall. 3 Lect. Basic features of laws and practices relating to contracts, torts, agency, property, water rights, business and government organizations, insurance, labor, governmental regulation of business, workmen's compensation, patents, ethical responsibilities of the engineer. Term paper: comparative analysis of the legal principles which affected the court decisions in some actual cases. Legal structure and prerogatives of authorities and other regional agencies.

2603. ENGINEERING ECONOMY (u)

Credit 3 hrs. Spring. Principles and techniques for making decisions about the economic aspects of engineering projects; the economic environment; choosing between alternatives; criteria for making decisions; time value of money; economic selection and operation; effect of income taxes; retirement and replacement; introduction to estimating costs of construction. Linear programming and critical path methods for economic analysis. Public project financing and economic analysis. Authorities and regional agencies.

[2604. CONSTRUCTION ENGINEERING (u,g)]

Credit 3 hrs. Fall. 3 Rec. Introduction to methods, equipment, and engineering principles and procedures involved in construction activities; major emphasis is on heavy construction such as large earth-moving projects, tunnels and caisson foundations. Not offered 1968–69.

2611. ECONOMICS OF ENVIRONMENTAL QUALITY MANAGEMENT (g)

Credit 4 hrs. Fall or spring. Prerequisite, 201 or equivalent. A graduate seminar devoted to theoretical welfare economics and its application to the management of environmental quality.

2612. APPLIED WELFARE ECONOMICS (g)

Credit 1–4 hrs. On demand. Prerequisite, permission of instructor. This seminar is an extension of 2611 with substantially greater emphasis on the application of welfare economics, statistics, and systems analysis to public investment decisions in areas such as water resources, transportation and public health.

2617. ENVIRONMENTAL SYSTEMS ANALYSIS I (g)

Credit 3 hrs. Fall. 3 Lect. Prerequisite, permission of instructor. 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 Lagrangian multipliers, dynamic programming, nonlinear programming. Application of systems analysis techniques to the solution of complex environmental, engineering-economic problems.

2618. ENVIRONMENTAL SYSTEMS ANALYSIS II (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 9320, 9522, 9530, or permission of instructor. Advanced topics in the application of mathematical programming and probability theory to the solution of environmental engineering problems.

Special emphasis on topics such as water-resource systems planning and management, transportation systems, public health systems, regional planning. Students will be expected to identify and solve practical problems using systems analysis.

2621. THEORY OF TRAFFIC FLOW (g)

Credit 3 hrs. Fall. One 2½ hr. meeting per week. Prerequisite, 9170 or equivalent, and consent of instructor. Study of traffic flow phenomena and related mathematical models. Car following models, hydrodynamic analogies, and other deterministic approaches. Probabilistic deductions, queuing models, Markov processes, simulation and other stochastic approaches. Flows in networks. Congestion and traffic assignment.

2622. TRANSPORTATION SYSTEMS ANALYSIS (g)

Credit 3 hrs. Spring. Prerequisite, 301, 2621, 9360, and 2617 or 9522 or equivalents. 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.

2626. TRAFFIC ENGINEERING (u,g)

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisite, permission of instructor. 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. HIGHWAYS AND AIRPORTS—PLANNING AND DESIGN (u,g)

Credit 3 hrs. Spring. Prerequisite, 2601, or permission of instructor. Route selection; design controls and criteria, including vehicle characteristics and highway capacity; sight distance, and horizontal and vertical control; right-of-way problems and access control; geometrics; at-grade intersection design; rotary and channelized intersection; grade separations and interchanges; regional systems of highways. Airport site selection; heliports; air traffic control. Terminal facilities.

2631. CONSTRUCTION MANAGEMENT (u,g)

Credit 3 hrs. Spring. Prerequisite, permission of instructor. 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.

[2632. CONSTRUCTION SYSTEMS ANALYSIS (g)]

Credit 3 hrs. Spring. One three-hour meeting per week. Prerequisite, 2617 or consent of instructor. 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 instructor. 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. Not offered 1968–69.

2691. ENVIRONMENTAL SYSTEMS DESIGN PROJECT (u,g)

Credit variable. On demand. Prerequisite, permission of instructor. May extend over two semesters. 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 (u,g)

Credit variable. On demand. Prerequisite preparation must be suitable to the investigation to be undertaken. With permission of the instructor. For investigation in depth of particular environmental systems problems.

2693. ENVIRONMENTAL SYSTEMS ENGINEERING COLLOQUIUM (u,g)

Credit 1–2 hrs. Fall or spring. Required of all graduate students with a major or minor in environmental systems engineering. Open to advanced undergraduates by permission of instructor. Preparation, presentation, and informal discussion of topics concerned with environmental systems. Distinguished visiting lecturers.

2694, 2695. SPECIAL TOPICS IN ENVIRONMENTAL SYSTEMS ENGINEERING (g)

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

In addition to the above list, courses offered throughout the University may be selected to support studies in the general subject area of environmental systems engineering. See especially the listings of other civil engineering departments as well as those of city and regional planning (College of Architecture, Art, and Planning), business and public administration, economics (College of Arts and Sciences), and operations research (College of Engineering).

Geotechnical Engineering

SOIL MECHANICS AND FOUNDATION ENGINEERING, SUBGRADES AND PAVEMENTS

2401. ELEMENTS OF SOIL MECHANICS (u)

Credit 3 hrs. Fall. 2 Lect., 1 Lab. 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)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 2401. 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)

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 2401. 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)

Credit 3 hrs. Spring. Prerequisite, 2410. 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)

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 2401. 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)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 2401. Principles of stability for earth and rock slopes; effects of pore water pressure; short and long term stability; problems of draw-down; 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)

Credit 3 hrs. Spring. 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)

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Intended for graduate students or upperclassmen in engineering and planning. Prerequisite, permission of the instructor. 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. Evaluation methods include field reconnaissance, interpretation of meterological, topographic, geological, and soil maps, aerial photography, engineering data, and subsurface exploration records.

2422. ADVANCED PHYSICAL ENVIRONMENT EVALUATION (u,g)

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Intended for graduate students or upperclassmen in engineering or planning. Prerequisite, 2421 or 2423 or permission of instructor. 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, and some emphasis on those related to special climatic regions such as tropical humid as well as arid regions.

2423. ANALYSES AND INTERPRETATION OF AERIAL PHOTOGRAPHS (u,g)

Preregistration required. Credit 3 hrs. Fall and spring. 2 Lect., 1 Lab. (The student is expected to pay the cost of field trips and aerial photographs for use in a term project, amounting to approximately $15.) 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)

Preregistration required. Credit 3 hrs. Fall and spring. 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. SUBGRADES AND PAVEMENTS FOR HIGHWAY AND AIRPORTS (u,g)

Credit 3 hrs. Offered upon sufficient demand, usually in spring. 2 Lec., 1 Lab. Prerequisite, 2601 or permission of the instructor. 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. LOW-COST ROADS (u,g)

Credit 3 hrs. Primarily for foreign students. Offered upon sufficient demand, usually in fall term. Prerequisite, consent of instructor. Principally directed study with one 2½ hour class session per week to be arranged. Rural road systems as instruments of economic development. Study of economic considerations in road system improvement; road improvement planning and programming; road location and geometric design; engineering soil characteristics; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces.

2445. FIELD PRACTICE IN GEOTECHNICAL ENGINEERING (u,g)

Credit 3 hrs. This course extends throughout the academic year with field studies 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. 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. Preparation for and reports on various sites is a requirement. 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. ENGINEERING MEASUREMENTS (u)

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Study of basic surveying instruments and of 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)

Credit 2 hrs. Fall and spring. 1 Lect., 1 Lab. Fundamentals of engineering measurements. Study of observations and errors. Principles of recording data. Use of steel tape, level, and transit. Optical tooling. Photogrammetry. Problems of particular interest to students in fields other than civil engineering.

2461. ELEMENTARY GEODESY (u,g)

Credit 3 hrs. Fall. 3 Lect. Principal problems of geodesy. Coordinate systems, reference datum. Geometric problems on earth ellipsoid. Geometric astronomy. Application of Bjerhammar singular matrix calculus; singular matrices to geodesy.

2462. GEOPHYSICAL GEODESY (u,g)

Credit 3 hrs. Spring. 3 Lect. 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 3 hrs. 2 Lect., 1 Lab. Prerequisite, 2451 or 2461. 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 2 hrs. 2 Lect. Prerequisite, 2451 or equivalent work in field astronomy. Study of the precise determination of latitude, longitude, and azimuth from astronomical observations. Night observation periods.

2465. ADVANCED ENGINEERING MEASUREMENTS (u,g)

Credit 3 hrs. Fall. Prerequisites, laboratory work involving physical measurements, Math. 293 or equivalent. 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)

Credit 3 hrs. 3 Lect. On demand. 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)

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Principles and practice of terrestrial and aerial photogrammetric mapping, including planning flights, control surveys, uncontrolled mosaics, radialline control, simple stereoplotting instruments, parallax distortions, graphical tilt determination, trimetrogen charting, and economics. A Balplex projection stereoplotter with three projectors is available for use.

2472. ADVANCED PHOTOGRAMMETRY (u,g)

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisite, 2471. An advanced study of photogrammetric principles including: controlled mosaics; rectification; graphical and instrumental aerotriangulation. Principles of photogrammetric plotters and systems and the economic relation of these to density of ground control, office methods, and personnel. Balplex projection plotter is used extensively.

2473. ANALYTIC AEROTRIANGULATION (u,g)

Credit 3 hrs. 3 Lect. Prerequisite, 2471. 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 3 hrs. 3 Lect. 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)

Credit 3 hrs. Spring. 1 Lect., 2 Labs. Prerequisite, 2451 or equivalent. 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)

Credit 1–6 hrs. On demand. Design problems frequently associated with the Master of Engineering Program.

2492. RESEARCH IN GEOTECHNICAL ENGINEERING (g)

Credit 1–6 hrs. On demand. 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 analyses or the development of design procedures.

2493. SEMINAR IN GEOTECHNICAL ENGINEERING (u,g)

Credit 1–2 hrs. On demand. 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)

Credit 1–6 hrs. On demand. 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.

Structural Engineering

2701. STRUCTURAL ENGINEERING I (u)

Credit 3 hrs. Fall. 2 Lect., 1 2-hour period. Prerequisites, Mech. 212 and coregistration in 6031. Evening prelims. First course in a four-course sequence of structural theory, behavior, and design. Basic structural concepts. External forces on simple structures under fixed and moving loads. Properties of structural metals. Behavior under load of metal members (beams, compression members, and beam-columns), including elastic and inelastic buckling.

2702. STRUCTURAL ENGINEERING II (u)

Credit 3 hrs. Spring. 2 Lect., 1 2-hour period. Prerequisites, 2701, 6031, and coregistration in 2751. Analysis of simple trusses under fixed and moving loads. Approximate analysis of building frames. Properties and behavior of reinforced concrete. Behavior under load of reinforced concrete beams, columns, and beam columns, including effects of prestressing. Computer applications to analysis and design.

2703. STRUCTURAL ENGINEERING III (u)

Credit 3 hrs. Fall. 2 Lect., 1 2-hour period. Prerequisite, 2702, 2751. Elastic displacements. Analysis of statically indeterminate structures by classical and modern methods. Collapse theory and plastic design concepts. Applications to steel and concrete structures.

2704. STRUCTURAL DESIGN (u)

Credit 3 or 4 hrs. Spring. 2 Lect., 1 or 2 2-hour periods. Prerequisite, 2703. Comprehensive design project drawing on material from previous courses (2701–03). Additional design topics such as structural models, shell structures, connections, composite construction.

2710. STRENGTH OF STRUCTURES (u,g)

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 2703, can be taken concurrently. 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)

Credit 3 hrs. Spring. Prerequisite, 2710. 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)

Credit 3 hrs. Fall and spring. 3 Lect. Prerequisites, 2703 or consent of instructor, and coregistration in C.S. 311. 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)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 2712. 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 deformation, finite displacements, dynamic response, and other special behavior mechanisms.

2714. STRUCTURAL MODEL ANALYSIS AND EXPERIMENTAL METHODS (g)

Credit 3 hrs. Spring. 2 Lect., 1 2-hr. period. Prerequisite, indeterminate analysis. Dimensional analysis and principles of similitude. Indirect model analysis of beams, frames, and trusses. Direct model analysis including loading and instrumentation techniques. Strain measurement and interpretation. Confidence levels for model results. Laboratory projects in elastic behavior and ultimate strength of model structures.

2715. NUMERICAL METHODS AND PROBABILITY (g)

Credit 3 hrs. Fall. Prerequisites, differential equations, consent of instructor, and coregistration in C.S. 311. Numerical integration techniques. Solution of linear systems. Finite difference techniques for boundary value problems. Eigenvalue determination. Introduction to probability concepts pertaining to structural analysis and design. Structural reliability; inference techniques; decision theory; stochastic processes.

2716. CONCRETE STRUCTURES I (u,g)

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 2703 or equivalent. 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)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 2703 or equivalent. 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)

Credit 3 hrs. each term. Fall and spring. Prerequisite, 2703 or equivalent. 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. 2719 not offered 1968–69.

2720. SHELL THEORY AND DESIGN (u,g)

Credit 3 hrs. Fall. Prerequisites, Mathematics 294 or equivalent and consent of instructor. 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)

Credit 3 hrs. Spring. Prerequisite, Mathematics 294 or equivalent and consent of instructor. 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 (u,g)

Credit 3 hrs. Fall. Prerequisites, Mechanics 211 and 212. Evolution of aerospace structural design concepts and the design cycle. Structural design criteria, environments, and specifications. Materials of construction and their properties. Modes of failure. Review of analytical problem areas, including dynamic response, aeroelasticity and thermal protection. Design charts for stressed skin construction.

2751. ENGINEERING MATERIALS (u)

Credit 3 hrs. Fall and spring. 2 Lect., 1 Lab. Prerequisite, 6311. 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)

Credit 2 hrs. Spring. 2 Lect. Prerequisite, 2001 or the equivalent. Topics in the field of concrete, such as history of cementing materials, air-entrainment, light weight aggregates, petrography, durability, chemical reactions, and properties of aggregates. Relationships 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)

Credit 3 hrs. Fall. 2 Lect. plus Conference. Open to graduate students in engineering or the physical sciences or to undergraduates by consent of the instructor. Internal structure of materials ranging from the amorphous to the crystalline state. Forces holding matter together versus forces causing deformation and failure. Correlation of the internal structures of materials with their physical and mechanical properties. Applications to various engineering materials.

2757. CIVIL ENGINEERING MATERIALS PROJECT (g)

On demand. Credit 1–6 hrs. Individual projects involving civil engineering materials.

2758. CIVIL ENGINEERING MATERIALS RESEARCH (g)

On demand. Hours and credit variable. Individual assignments, investigations and/or experiments with civil engineering materials.

2791. DESIGN PROJECT IN STRUCTURAL ENGINEERING (g)

(Meets project requirement for M.Eng. degree.) Credit 1 hr. fall and 3 hrs. spring; both terms required. 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. 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 in the nature of 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)

Credit 1–3 hrs. Spring. Open to qualified seniors and graduate students. 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. 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)

Credit 3 hrs. Fall. 3 Lect.-Rec. Fluid properties, hydrostatics, the basic equations of fluid flow, potential flow, dimensional analysis, flow in conduits, open channel flow.

2302. HYDRAULIC ENGINEERING (u)

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Prerequisite, 2301. Free surface and pipe flow, fluid meters and measuring devices, hydraulic machinery, unsteady flow, network analysis. The laboratory will include a number of experiments in fluid mechanics and hydraulic engineering.

2303. HYDROLOGY (u,g)

Credit 2 hrs. Fall. 2 Lect.-Rec. Prerequisite, 2301. Introduction to hydrology including topics on precipitation, evapotranspiration, ground water, surface water, sedimentation.

2312. EXPERIMENTAL AND NUMERICAL METHODS IN FLUID MECHANICS (u,g)

Credit 2 hrs. Fall and spring. Prerequisite, 2302 or permission of instructor. Primarily a laboratory course for undergraduates and graduates; may be repeated for credit on permission of the instructor. Emphasis is on planning and conducting laboratory and field experiments and on numerical computation. Each section is limited to four students.

2315. ADVANCED FLUID MECHANICS I (g)

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 2301. 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)

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 2315. 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)

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 2315 or permission of instructor. 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.

2320. SURFACE-WATER HYDROLOGY (g)

Credit 3 hrs. Fall. Prerequisite, 2301. Physical and statistical analysis relating to hydrologic processes. Hydrometerology and evaporation. Surface runoff, base flow, and storage routing in linear and non-linear systems. Unit hydrograph theory.

2321. FLOW IN POROUS MEDIA (g)

Credit 3 hrs. Spring. Prerequisite, 2301 (also recommended, 2315). 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, of infiltration and of ground water recharge, and of other steady state and transient seepage problems in fully and partially saturated materials.

[2331. RIVER AND COASTAL HYDRAULICS (u,g)]

Credit 3 hrs. Spring. Prerequisite, 2302 or permission of instructor. The first part of this course deals with the hydraulics of fixed bed channels including the specific energy concept, secondary currents, rapid flow problems, artificial obstructions in channels, and the general problems of frictional resistance. In the second part of the course, attention is paid to coastal and oceanographical engineering problems including the theory of waves, breaking of waves, wave refraction and wave diffraction. Not offered 1968–69.

2332. SEDIMENT TRANSPORT (u,g)

Credit 3 hrs. Fall. Prerequisite, 2302 or permission of instructor. Hydraulics of channels with a movable bed including particle mechanics, critical tractive force theory, the DuBoys Problem, the Swiss formulas, Einstein's Bedload theory, the suspension and saltation theory, calculation of total sediment loads. Interesting problems in fluvial hydraulics will be included.

2391. PROJECT (g)

Offered on demand. Hours and credit variable. 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. 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)

Credit 1 hr. Fall and spring. Open to undergraduates and graduates and required of graduate students majoring in hydraulics or hydraulic engineering. Topics of current interest in fluid mechanics, hydraulic engineering, and hydrology.

2394. SPECIAL TOPICS IN HYDRAULICS (g)

Offered on demand. Hours and credit variable. Special topics in fluid mechanics, hydraulic engineering, or hydrology.

SANITARY (ENVIRONMENTAL) ENGINEERING AND WATER RESOURCE SYSTEMS ENGINEERING

2501. WATER SUPPLY AND WASTE-WATER ENGINEERING (u)

Credit 3 hrs. Fall. 2 Lect., 1 Lab or Comp. Prerequisites, 2301, 2302. Introduction to water resources engineering, including water supply and water quality control. Principles applicable to the disposal, assimilation, and fate of municipal and industrial wastes in the environment. Problems in the analysis and design of water transmission and distribution systems, and of waste-water and storm-water collection and waste management systems.

2502. WATER AND WASTE-WATER TREATMENT (u,g)

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisite 2301. Study of the microbiological, chemical, and physical phenomena underlying the treatment of water and of municipal and industrial waste-water. Laboratory studies of these phenomena.

2510. CHEMISTRY OF WATER AND WASTE-WATER (u,g)

Credit 3 hrs. Fall. 2 Lect.-Rec., 1 Lab. Prerequisite, one year of college chemistry. Principles of chemistry applicable to the understanding, design and control of water and waste-water treatment processes and to reactions in receiving waters. Analytical methods applicable to the measurement and control of air and water quality.

2512. MICROBIOLOGY OF WATER AND WASTE-WATER (u,g)

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Introduction to the characteristics of microorganisms, their interaction with the environment, and their effect on water quality. Their role in the oxidation of organic substances in waste-water treatment and in receiving waters. Kinetics of microbial substrate assimilation and growth. Bacteriological, biological, and limnological parameters of water quality and their measurement.

2513. TREATMENT PROCESSES (u,g)

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 2502 or equivalent. Analysis and design of processes for the removal of impurities from water and from municipal and industrial waste-water. Theoretical and applied aspects of treatment process design, including reaction kinetics, transfer phenomena, and the mechanics of fine particles.

2514. ASSIMILATION OF WASTES IN WATER (u,g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, appropriate undergraduate course. Capacity of water resources to assimilate gaseous, liquid, and particulate wastes. Phenomena pertinent to the dispersion and stabilization of wastes in water. Analog and digital computer methods. Emphasis on the advanced literature.

2515. WATER RESOURCES PROBLEMS AND POLICIES (u,g)

Credit 3 hrs. Fall. Lect.-Discuss. Prerequisite, permission of the instructor. 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)

Credit 3 hrs. Spring. Prerequisites, Econ. 301; 2617 or 9522; 9360 or 9460; or permission of instructor. Application of economic theory and systems analysis to problems in water resources planning and management. Deterministic and stochastic models. Review of the current literature.

2520. ENVIRONMENTAL HEALTH ENGINEERING (u,g)

Credit 3 hrs. Spring. 3 Lect., Reports. Prerequisite, 2501, or equivalent, or permission of the instructor. Concepts of environmental health, principles of epidemiology and of toxicology. Introduction to radiological health. Consideration of problems in environmental control with emphasis on waste management, water quality control, air quality control, and solid waste disposal.

2530. SOLID WASTE MANAGEMENT (u,g)

Credit 3 hrs. Spring. 3 Lec., Reports. Prerequisite, permission of the instructor. Study of municipal, industrial, and agricultural solid waste. Emphasis on waste characteristics, methods of treatment and disposal, interrelationships with air, water, and land environment. Intended primarily for graduate students but open to qualified undergraduates.

2532. ENVIRONMENTAL QUALITY ENGINEERING (u,g)

Credit 3 hrs. Fall. Lect.-Discuss., reports and field trips. Open to students who are not in civil engineering. Environmental health concepts and methods, and their application to environmental planning and control at the subdivision, municipal, and metropolitan levels. Introduction to: water resource planning and development; water quality control; water supply; municipal, industrial and private waste-water disposal; air quality control; solid waste disposal and radiological health.

2545. WATER RESOURCES PLANNING SEMINAR (u,g)

Credit 3 hrs. Spring. Prerequisite, 2515 or permission of the instructor. The concepts, processes, and techniques of regional, multi-purpose river basin planning and development. The case study method, including the preparation of an integrated, comprehensive report for the study area, is followed.

2547. SEMINAR IN WATER RESOURCES SYSTEMS ANALYSIS (g)

Credit 4 hrs. Spring or fall. Prerequisite, permission of the instructor which will be based on the student's ability to contribute substantially to the seminar. An interdisciplinary approach to the solution of a complex problem in water resources engineering involving the application of systems analysis, statistics, economic theory, hydrology and hydraulic and sanitary engineering. Each student will study and discuss a particular aspect of the problem. The results of the individual studies should contribute to the solution of the overall problem. Taught by engineering and economics faculty.

2591. DESIGN PROJECT IN WATER RESOURCES ENGINEERING OR IN SANITARY ENGINEERING (g)

On demand. Credit variable. Prerequisites, 2501 or 2502 or equivalent. 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 of laboratory apparatus of special interest.

2592. SANITARY ENGINEERING RESEARCH (g)

On demand. Credit variable. Prerequisites will depend upon the particular investigation to be undertaken. 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)

Credit 1–2 hrs. Fall and spring. Required of all graduate students taking a major or minor in sanitary engineering; open to undergraduates by permission of instructor. Preparation, presentation, and discussion of topics and problems of current interest 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. Supervised study in special topics not covered in formal courses.

COMPUTER SCIENCE

201. SURVEY OF COMPUTER SCIENCE (u)

Credit 3 hrs. Spring. M W F 8:00. Introduction to the structure and use of the modern digital computer. This course is intended to be a nonmathematical treatment of the material, with emphasis 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.

311. INTRODUCTION TO COMPUTER PROGRAMMING (u)

Credit 2 or 3 hrs. Either term. T Th 11:15. Notations for describing algorithms, analysis of computational problems. Application of the (FORTRAN IV, PL/I) programming language to solve simple numerical and nonnumerical problems using a digital computer.

385. AUTOMATA (u)

Credit 3 hrs. Spring. Prerequisite, Mathematics 294, 222 or equivalent. M W F 10:10. The capabilities, limitations and structures of finite automata, Turing machines and other abstract computing devices will be studied. Applications to questions of undecidability and artificial intelligence.

401. COMPUTER ORGANIZATION AND PROGRAMMING (g)

Credit 4 hrs. Either term. Prerequisite, Mathematics 221, 293 or equivalent. T Th 11:15, W 2:30–4:25. Characteristics and structure of digital computers. Programming in assembly and higher-order languages. Representation of data, index registers and indirect addressing, program organization, macro operations, recursive procedures, interpretive routines, auxiliary storage and input-output, operating systems.

404. ADVANCED COMPUTER PROGRAMMING (g)

Credit 4 hrs. Spring. Prerequisite, 401 or consent of instructor. T Th 1:25, F 2:30. This course is 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. Students are expected to participate in a large systems-programming design and implementation project.

411. INFORMATION AND COMPUTER STRUCTURES (g)

Credit 4 hrs. Fall. Prerequisite, 401 or equivalent. T Th 9:05, W 2:30. Fundamentals of computer organization and the representation of structured operands in computers. Information flow during instruction execution; addressing structures, symbol table techniques. Algorithms for the manipulation of arrays, trees, strings, lists. Programming language structure; recognition and analysis systems. Time-sharing computer organization, paging, segmenting, and core management.

412. COMPUTER LANGUAGES AND COMPILERS (g)

Credit 4 hrs. Spring. Prerequisite, 411 or consent of instructor. M W F 1:25. Concerned with the theory and techniques of programming languages and systems for large-scale digital computer systems. Topics include comparison of structure and form of assemblers, interpreters, compilers and list processors; formal definition of algorithmic languages and techniques used in compilation. Students will design and implement several simple languages during the term.

413. SYSTEMS PROGRAMMING (g)

Credit 4 hrs. Fall. Prerequisite, 412 or consent of instructor. M W F 1:25. Brief review of batch process programming systems, their components, operating characteristics, user services and their limitations. Implementation techniques for parallel processing of I/O and interrupt handling. Overall structure of multiprogramming systems on large-scale multiprocessor hardware configuration. Details on addressing techniques, core management, file system design and management, system accounting, and other user-related services. Command languages and the embedding of subsystems. Operating characteristics (parameters) of large-scale systems.

416. OPERATIONS RESEARCH MODELS FOR COMPUTER AND PROGRAMMING SYSTEMS

Credit 4 hrs. Spring. Prerequisites: 411 and a course in probability (e.g., Math 371 or Engineering 9460), or consent of instructor. T Th 10:10, occasionally W 2:30. 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. Queueing 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.

[417. ADVANCED INFORMATION PROCESSING (g)]

Credit 4 hrs. Fall. Prerequisite, 401 or equivalent experience. T Th 9:05, W 2:30. Provides a theoretical foundation in information processing, with emphasis on the use of computers for the solution of primarily nonnumeric problems. Covered are recent developments in processor organization and processing methods, compiling and translating systems, search and sorting techniques. Students will run individual term projects on the available computing equipment. Not offered 1968–69.

420. COMPUTER APPLICATIONS OF NUMERICAL ANALYSIS (g)

Credit 4 hrs. Fall. Prerequisites, Mathematics 222 or 294, and Computer Science 311 or equivalent programming experience. M W F 10:10. Modern computational algorithms for the numerical solution of a variety of applied mathematics problems are presented; 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 polynominal 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)

Credit 4 hrs. a term. Throughout the year. Prerequisite, Mathematics 412, 416, 422, or consent of instructor. M W F 9:05. A mathematically rigorous treatment of numerical analysis. Covers the topics of Computer Science 420 in a more complete fashion with emphasis on careful analytical derivation of algorithms, proofs of convergence and error analysis. Includes some computer programming projects.

435. INFORMATION ORGANIZATION AND RETRIEVAL (g)

Credit 4 hrs. Spring. Prerequisite, 401 or equivalent. T Th 9:05, occasionally W 2:30. Covers all aspects of automatic language processing on digital computers, with emphasis on applications to information retrieval. Analysis of information content by statistical, syntactic and logical methods. Dictionary techniques. Automatic retrieval systems, question-answering systems. Evaluation of retrieval effectiveness.

[441. HEURISTIC PROGRAMMING (g)]

Credit 4 hrs. Spring. Prerequisites, 401 and 411. Comparison of heuristic and algorithmic methods. Justification of the need for heuristic approach and discussion of the objectives of work in artificial intelligence and in simulation of cognitive behavior. Discussion of research projects using heuristic programming techniques. Not offered 1968–69.

485. THEORY OF AUTOMATA I (g)

Credit 4 hrs. Fall. Prerequisite, Computer Science 401 or consent of instructor. M W F 11:15. 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)

Credit 4 hrs. Spring. Prerequisite, 485 or consent of instructor. M W F 11:15. Topics include context-free and context-sensitive languages and their relation to push-down and linearly-bounded automata. Quantitative aspects of Turing machine computations: time and memory bounded computations with applications to language processing and classification of other automata and computations.

487. FORMAL LANGUAGES (g)

Credit 4 hrs. Fall. Prerequisite, 486 or consent of instructor. M W F 2:30. 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)

Credit 4 hrs. Spring. Prerequisite, Computer Science 401, 485, Mathematics 481, or consent of instructor. T Th 9:05. 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.

521. NUMERICAL ANALYSIS OF LINEAR AND NONLINEAR SYSTEMS OF EQUATIONS (g)

Credit 4 hrs. Spring. Prerequisite, Computer Science 422. M W F 9:05. Topics include recent methods for the solution of linear systems and eigenvalue, eigenvector determination; global convergence theorems for nonlinear systems, Newton-Kantorovich theory and its variations; function minimization.

[523. NUMERICAL SOLUTION OF ORDINARY DIFFERENTIAL EQUATIONS AND INTEGRAL EQUATIONS (g)]

Credit 4 hrs. Fall. Prerequisite, Computer Science 422. M W F 11:15. Topics include solution of n-th order nonlinear initial value problems and boundary value problems; single step methods; predictor-corrector techniques; stability, accuracy and precision of methods; eigenvalue problems; solution of integral equations having constant or variable limits; finite difference and iterative methods; singular and nonlinear integral equations. Not offered 1968–69.

[525. NUMERICAL SOLUTION OF PARTIAL DIFFERENTIAL EQUATIONS (g)]

Credit 4 hrs. Spring. Prerequisite, Computer Science 523. M W F 11:15. General classification; solution by method of characteristics; finite-difference methods for hyperbolic and elliptic equations; parabolic equations in two dimensions; direct solution of elliptic finite-difference equations; iterative methods for the solution of elliptic equations; block methods for large systems; singularities in elliptic equations; stability in relation to initial value problems and nonlinear discretization algorithms. Not offered 1968–69.

[527. NUMERICAL METHODS IN APPROXIMATION THEORY (g)]

Credit 4 hrs. Spring. Prerequisite, Computer Science 422. M W F 9:05 L_p norms; least-square approximation and orthogonal functions; Tchebycheff, asymptotic, rational and continued fraction approximations; the quotient-difference algorithm; methods of descent and ascent. Not offered 1968–69.

587. COMPUTATIONAL COMPLEXITY (g)

Credit 4 hrs. Fall. Prerequisite, 486, 488, or consent of instructor. T Th 9:05. General measures of computational complexity and methods of classifying computable (recursive) functions. Examples of topics include restricted Turing machines, time and memory bounded computations, as well as quantitative results about formal languages.

590. SPECIAL INVESTIGATIONS IN COMPUTER SCIENCE (g)

Credit and sessions to be arranged. Throughout the year. Offered to qualified students individually or in small groups. Directed study of special problems in the field of computer science. (Register only with the registration officer of the department.)

591. COMPUTER SCIENCE GRADUATE SEMINAR (g)

Credit 1 hr. Throughout the year. For graduate students interested in computer science. Th 4:30–6:00. Staff, visitors and students. A weekly meeting for the discussion and study of important topics in the field.

611. SEMINAR IN PROGRAMMING (g)

Credit 4 hrs. Spring. Prerequisite, 411 or consent of instructor.

621. SEMINAR IN NUMERICAL ANALYSIS (g)

Credit 4 hrs. Fall. Prerequisite, consent of instructor.

635. SEMINAR IN INFORMATION ORGANIZATION AND RETRIEVAL (g)

Credit 4 hrs. Fall. Prerequisite, Computer Science 435.

681. SEMINAR IN AUTOMATA THEORY (g)

Credit 4 hrs. Spring. Prerequisite, 486 or consent of instructor.

DIGITAL SYSTEMS SIMULATION (Industrial Engineering 9580)

Credit 4 hrs. Fall. Prerequisite, Computer Science 401 and Operations Research 9470, or consent of instructor. 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 the CLP and SIMSCRIPT languages. Problems in the design of effective investigations using simulation; statistical considerations when sampling from a simulated process.

DATA PROCESSING SYSTEMS (Industrial Engineering 9589)

Credit 3 hrs. Fall. Prerequisite, Computer Science 401 or consent of instructor. Concerned with 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.

SWITCHING SYSTEMS I (Electrical Engineering 4487)

Credit 3 hrs. Fall. Prerequisite, 4322 or consent of instructor. Switching algebra; switching devices; logical formulation and realization of combinational switching circuits; minimization aids; number representation and codes; simple memory devices; synchronous sequential circuits; counters; shift registers, and arithmetic units in a digital computer.

SWITCHING SYSTEMS II (Electrical Engineering 4488)

Credit 3 hrs. Spring. Prerequisite, 4487 or equivalent. Synchronous and asynchronous sequential circuits, formulation and optimization; large-scale memory units, selection and control; further discussion of arithmetic units; integrated study of switching systems including general-purpose digital computer, control switching, and communication switching; introduction to the general theory of learning machines.

ELECTRICAL ENGINEERING

Required Courses

SYSTEMS SEQUENCE

4301–4302. ANALYSIS OF ELECTRICAL SYSTEMS I AND II (u)

Credit 4 hrs. 3 Lect., 1 Rec.-Comp. Prerequisites, Electrical Science 242 and Mathematics 294 or equivalents. 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; proper graphs. Intentional feedback; sensitivity. Root locus and Nyquist plots. Intentional oscillation; conditions for instability; piecewise linear models and networks. Phase plane analysis. Dynamical equations for mechanical and other systems. Passive and active analogs. Analysis of elementary electromechanical systems. Coupling fields, forces, and motion for linear and nonlinear materials. Lagrangian and Hamiltonian formulations of system equations. Messrs. Thorp and Pottle.

4401. DETERMINISTIC SIGNALS IN LINEAR SYSTEMS (u)

Credit 4 hrs. Fall. 3 Lect., 1 Rec-Comp. Prerequisite, 4302. 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 A. Papoulis, *The Fourier Integral and its Applications*. Mr. Sloane.

4402. RANDOM SIGNALS IN LINEAR SYSTEMS (u)

Credit 4 hrs. Spring. 3 Lect., 1 Rec.-Comp. Prerequisite, 4401. Analysis of linear systems subjected to random excitation. Applications to communication and control systems. Introduction to probability, random variables, expectations, random vectors. Measurement of moments and probabilities. Least mean square estimation, matched filters, and channel capacity. Random processes, correlation functions, and power spectral densities. Input-output relations in linear systems. At the level of Davenport and Root, *Random Signals and Noise*. Mr. Fine.

ELECTROPHYSICS SEQUENCE

4311–4312. ELECTROMAGNETIC FIELDS AND WAVES (u)

Credit 4 hrs. Throughout the year. 3 Lect., 1 Rec.-Comp. Prerequisites, Electrical Science 242 or 244 and Mathematics 294 or equivalent. Foundations of electromagnetic theory for static and dynamic fields with applications to waves, circuits, and devices. Topics treated will include: one-dimensional waves and transmission lines; vector calculus; polarization of dielectric and magnetic materials; boundary-value problems, separation of variables, orthonormal functions; field energy and stresses; Maxwell's equations, wave solutions, retarded potentials, applications to circuits including skin effect; electromechanics of rigid conductors and continuous media, elements of magnetohydrodynamics; radiation, elementary antennas; wave propagation in periodic structures; reflection and refraction of waves, wave-guides, cavities, coupled modes; frequency dependence of conductivity and permittivity, plasmas; wave propagation in gyrotropic media and in electron steams. At the level of Ramo, Whinnery, and Van Duzer, *Fields and Waves in Communication Electronics.* Mr. McIsaac.

4411. QUANTUM THEORY AND APPLICATIONS (u)

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. Prerequisite, 4311, 4312 or equivalent. Introduction to nonrelativistic quantum theory with emphasis on applications; 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; central field model of atomic structure; antisymmetry and the Pauli exclusion principle. At the level of White, *Basic Quantum Mechanics.* Mr. Liboff.

4412. SOLID STATE PHYSICS AND APPLICATIONS (u)

Credit 4 hrs. Spring. 3 Lect., 1 Rec.-Comp. Prerequisite, 4411 or equivalent. Introduction to solid state physics and application to electronic devices; crystal symmetry and structure; x ray diffraction, reciprocal lattice; free electron theory, photo emission, thermionic emission, field emission, Drude theory of electrical conductivity; band theory; semiconductors and semiconductor devices including p-n junctions, transistors, avalanche and hot electron devices; dielectric properties of solids; magnetism; superconductivity. At the level of C. Kittel, *Introduction to Solid State Physics* (3rd ed.). Mr. Ballantyne.

LABORATORY SEQUENCE

4321. ELECTRICAL LABORATORY I (u)

Credit 4 hrs. Fall. 1 Lect., 2 Lab. Basic electrical and electronic instrumentation and measurements involving circuits and fields of both active and passive elements; and an experimental introduction to solid state and high vacuum devices.

4322. ELECTRICAL LABORATORY II (u)

Credit 4 hrs. Spring. 1 Lect., 2 Lab. Basic experiments concerning transmission lines, high-frequency measurements and techniques, amplifiers and oscillators, nonlinear and negative-resistance devices, and energy-conversion methods.

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

4501. SYSTEMS WITH RANDOM SIGNALS AND NOISE (g)

Credit 4 hrs. Fall. 3 Lect., 1 Rec. Prerequisite, 4402 or equivalent. Linear-systems and signals; probability and random variables; random processes in communication systems; spectral analysis of random processes; filtering of random signals; band-pass signals and noise; envelope detection of signals and noise; post detection filtering; nonlinear receiver operations; modulation systems; time and frequency multiplex systems; noise in analog modulation systems. Mr. McGaughan.

4502. STATISTICAL ASPECTS OF COMMUNICATION (g)

Credit 4 hrs. Spring. 3 Lect., 1 Rec. Prerequisite, 4501. Digital transmission systems; the discrete transmission channel; elements of information transmission and coding; information capacity; system optimization; linear least squares prediction and smoothing; matched filters; optimum receivers; hypothesis testing; parameter estimation; the matched filter and the correlation receiver; wave form systems and signal design; error probabilities and error bounds for various systems. At the level of Wozencraft and Jacobs, *Principles of Communication Engineering.* Mr. McGaughan.

4503. THEORY OF LINEAR SYSTEMS I (g)

Credit 4 hrs. Fall. 3 Lect. Prerequisite, 4401, or consent of instructor. 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 Schwarz and Friedland, *Linear Systems.* Mr. Szentirmai.

4504. THEORY OF NONLINEAR SYSTEMS I (g)

Credit 4 hrs. Spring. 3 Lect. Prerequisite, 4503, 4501, 4571, or consent of instructor. Lagrangian formulation. Analysis of first and second order nonlinear systems with applications. Phase-plane analysis of autonomous systems; singular points, limit cycles, and equilibrium states; theories of Bendixson, Lienard, and Poincare; relaxation behavior in the phase plane; perturbation theory, existence, convergence, and periodicity of perturbation series; methods of van der Pol and of Krylov and Bogoliubov. Forced nonlinear systems, harmonics, subharmonics, jump phenomena, and frequency entrainment; periodic systems, Floquent theory, Mathieu-Hill theory, applications to the stability of nonlinear systems and to parametrically-excited systems. Mr. Szentirmai.

4507–4508. RANDOM PROCESSES IN ELECTRICAL SYSTEMS (g)

Credit 4 hrs. Fall and spring. 3 Lect. The concepts of randomness and uncertainty and their relevance to the design and analysis of electrical systems. An axiomatic characterization of random events. Numerically valued events: 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. Convergence of sequences of random variables: laws of large numbers and central limit theorems. More general collections of random variables, random processes. Random processes as signal or system models and their specification. Sample function behavior. Markov processes, particularly chains and the Poisson process. Stationarity and ergodicity. The Gaussian process. Wide sense stationary processes: correlation functions, spectra. Representations of random processes. Transformations of random processes by nonlinear devices and filters. Optimum filtering theories. Messrs. Fine and Berger.

4571. NETWORK ANALYSIS (g)

Credit 4 hrs. Fall. 3 Lect. Open to qualified seniors. Introduction to network topology. Scattering, immittance, hybrid, and state space formalisms for networks. Steady state analysis and power transfer in n-port networks including nonreciprocal and active structures. Scattering properties and realizability theorems for lossless multiport junctions. Analysis of transmission line networks. At the level of Carlin and Giordano, *Network Theory: An Introduction to Reciprocal and Non-Reciprocal Circuits.* Mr. Carlin.

4572. NETWORK SYNTHESIS (g)

Credit 4 hrs. Spring. 3 Lect. Prerequisite, 4571, 4503, or consent of instructor. 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. Mr. Carlin.

[4601. THEORY OF NONLINEAR SYSTEMS II (g)]

Credit 4 hrs. Spring. 3 Lect. Prerequisite, 4504 or consent of instructor. Nonautonomous and higher order nonlinear systems with applications; representation of systems with several degrees of freedom; approximations; use of Liapunov functions in system stability determination and design; describing functions and Aizerman's hypothesis, theory of Lur'e-Letov for nonlinear control; asymptotic expansions for the period behavior of systems under the influence of periodic external forces; method of averaging; systems with slowly varying parameters, Manley-Rowe relations; orthogonal representation of nonlinear systems; nonlinear filters and compensating systems, system optimization. Not offered in 1968–69.

[4603. THEORY OF LINEAR SYSTEMS II (g)]

Credit 4 hrs. Spring. 3 Lect. Prerequisite, 4503. Not offered 1968–69.

ELECTROMAGNETIC THEORY

4511. ELECTRODYNAMICS (g)

Credit 4 hrs. Fall. 3 Lect., 1 Rec. Prerequisite, 4312 or equivalent and co-registration in Mathematics 421 or equivalent. Foundations of electromagnetic theory. Statics: Multipole distributions, images and potential theory. Elements of magnetostatics. Maxwell's equations. Wave guides and cavities. Stress-energy tensor. Gauge invariance. Poynting's theorem. Radiation theory. Postulates of relativity. Lienard-Wiechert potentials. Synchrotron and Cherenkov radiation. Energy and angular momentum of the radiation field. Radiative reaction force. Electromagnetic force. Mr. McIsaac.

4514. MICROWAVE THEORY (g)

Credit 4 hrs. Spring. 3 Lect., 1 Rec. Prerequisite, 4511 or equivalent. Theory of passive microwave devices for propagating, storing, coupling, or radiating microwave energy, including the theory of uniform and periodic waveguides, cavities, junctions, and antennas; application of inhomogeneous, anisotropic, dispersive, or nonlinear dielectric and magnetic materials to microwave devices; circulators, isolators, tunable filters, limiters, artificial dielectrics; techniques of analysis, including use of orthogonal functions, perturbation theory, variational techniques, Green's functions, and symmetry principles. Mr. McIsaac.

4567. ANTENNAS AND RADIATION (u,g)

Credit 3 or 4 hrs. (4 hrs. with lab) Spring. 3 Lect. Prerequisite, 4312, 4401 or equivalent. Formulation of the electromagnetic field in terms of vector and scalar potentials; radiation from elemental electric and magnetic dipoles. Linear radiators: radiation from short dipoles, small loops; resonant wire antennas; long wire antennas, linear arrays and pattern synthesis; impedance properties of wire antennas, including mutual impedance, parasitic elements; wire receiving antennas. Aperture antennas: uniqueness theorem for vector fields, equivalence and induction principles; radiation from open-ended waveguides, horn antennas, reflector antennas; Babinet's principle; slot antennas. Laboratory experiments will be conducted on an antenna range. At the level of Jordan, *Electromagnetic Waves and Radiating Systems.* Messrs. Brice and Ott.

[4568. ADVANCED ANTENNA METHODS AND PROBLEMS (g)]

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 4567 or equivalent, 4511 or equivalent. Huygens' principle for electromagnetic fields, application to problems of diffraction and aperture radiators; surfacewave antennas; various specialized antennas, helical, log periodic, radio astronomy systems, space and satellite systems; radiation in dielectric and plasma media, including media in motion; antenna thermodynamics. Not offered 1968–69.

LABORATORY

4421–4422. ADVANCED ELECTRICAL LABORATORY (u)

Credit 4 hrs. May be taken in the fall and spring terms consecutively or separately. 1 Lect., 2 Lab. Prerequisite, 4322 or consent of instructor. Advanced experiments concerning a wide range of topics appropriate to electrical engineering, and 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 synchronization, noise properties, 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 a-c and d-c machines. The student is expected to perform three or four experiments per term, selected to meet his needs. Emphasis is placed upon independent work. Mr. Nation and Staff.

4520. GRADUATE LABORATORY (g)

Credit 3 hrs. Fall normally, but either term if demand is sufficient. 1 Lab. Choice of three to five experiments in the fields of solid-state and quantum electronics, microwave electronics, vacuum and physical electronics, optics, radio and communication circuits, networks, transmission lines, antennas, propagation of electromagnetic waves, plasma physics, and electrical machinery. Mr. Eastman.

ELECTRONICS

4431–4432. ELECTRONIC CIRCUIT DESIGN (u)

Credit 3 hrs. per term. Throughout the year. 2 Lect.-Rec., 1 Lab. Prerequisite, 4322. 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 Millman and Taub, *Pulse Digital and Switching Waveforms.* Mr. Bryant.

4433. SEMICONDUCTOR ELECTRONICS I (u,g)

Credit 4 hrs. Fall. 3 Lect., 1 Lab. Prerequisite, 4302, 4322. 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 the Semiconductor Electronics Education Committee (S.E.E.C.) Series, Vols. 1–4. Mr. Ankrum.

4434. SEMICONDUCTOR ELECTRONICS II (u,g)

Credit 4 hours. Spring. 3 Lect., 2 Lab. Prerequisite, 4433. 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. At the level of the S.E.E.C. Series. Vols. 5 and 6; and Gentry, *Semiconductor Controlled Rectifiers: Principles and Application of p-n-p-n Devices.* Mr. Ankrum.

4531. QUANTUM ELECTRONICS I (g)

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. Prerequisites, 4311, 4412, and Physics 443 or 4411. A detailed treatment of the physical principles underlying microwave and optical masers and related fields. Topics will include a brief review of quantum mechanics and the theory of angular momentum; spectroscopy of free atoms and ions with particular emphasis on the application of the results to neutral and ionized noble gas masers; theory of interaction of radiation and matter; quantum theory of coherence; a thorough study of the steady-state and dynamic characteristics of microwave and optical masers. At the level of Yariv, *Quantum Electronics.* Mr. Tang.

4532. QUANTUM ELECTRONICS II (g)

Credit 4 hrs. Spring. 3 Lect., 1 Rec.-Comp. Prerequisite, 4531 or consent of instructor. A continuation of the treatment of the physical principles underlying masers and related fields. Topics will include a consideration of microwave and optical spectroscopy of impurity ions in solids with particular emphasis on the application of the results to microwave and optical solid state masers; density matrix and its applications in the study of masers and related problems; nonliner optical phenomena and multiplephoton processes; interaction of intense light waves with molecular vibrations and elastic waves; theory and properties of molecular and semiconductor masers; characteristics of optical resonators. At the level of Yariv, *Quantum Electronics.* Mr. Tang.

4535. SOLID STATE DEVICES I (g)

Credit 4 hrs. Fall. 3 Lect. Prerequisite, 4412 or equivalent. Available to fourth-year students with permission of instructor. 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, 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: Shottky diode, Shottky triode. Emphasis is placed on determining the factors determining performance capabilities. Equivalent circuits are developed. The student will carry out either a term laboratory project or prepare a term paper on an appropriate contemporary topic. The course is presented at the level of Moll, *Physics of Semiconductors* (McGraw Hill), and of current papers published in the *IEEE Transactions on Electron Devices*. Mr. Dalman.

4536. SOLID STATE DEVICES II (g)

Credit 4 hrs. Spring. 3 Lect. Prerequisite, 4551 or equivalent. Available to fourth-year students with permission of instructor. 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 (Llewellyn-Peterson), space-charge wave and coupled-mode analysis. Devices studied include: avalanche microwave diode (Read diode), microwave transistors, tunnel diodes, Gunn oscillators, injection lasers. Emphasis is placed on determining the factors that determine the performance capabilities. Equivalent circuits are developed. The student will carry out either 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*. Mr. Dalman.

4538. ELECTROMAGNETIC PROPERTIES OF SOLIDS (g)

Credit 4 hrs. Spring. 3 Lect., 1 Rec. Prerequisites, Physics 454 or 4412 and 4511 (Electrodynamics) or consent of instructor. Microscopic interpretation of complex permittivity and permeability: electronic, atomic, orientation and space charge polarization; interaction of elementary magnetic moments; dielectric dispersion via resonance and relaxation, plasma resonance; quantum theory of dielectric constant; local internal field and spontaneous ordering; introductory lattice dynamics, lattice frequency spectrum, introductory group theory and application to derivation of selection rules for infrared and Raman active normal modes; extended frequency analysis of vibrational spectra. Mr. Ballantyne.

4631–4632. THE PHYSICS OF SOLID STATE DEVICES (g)

Credit 2 or 3 hrs. per term. Fall and spring. 2 Lect. Prerequisite, 4536 or permission of instructor. 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 aspects of 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. Mr. Lee.

POWER SYSTEMS AND MACHINERY

[4441. CONTEMPORARY ELECTRICAL MACHINERY I (u,g)]

Credit 3 hrs. Fall. 2 Lect.-Rec., 1 Lab.-Comp. Prerequisite, 4302. Emphasis on engineering principles. Real and reactive power requirements of core materials with symmetrical and with 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. Not offered 1968–69.

[4442. CONTEMPORARY ELECTRICAL MACHINERY II (u,g)]

Credit 3 hrs. Spring. 2 Lect-Rec., 1 Lab.-Comp. 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. Not offered 1968–69.

4443. POWER SYSTEM EQUIPMENT (u,g)

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Prerequisite, 4302. System equipment and control parameters are studied. Test requirements for electrical apparatus for conventional and nuclear electrical power production and distribution are considered. Prime movers, generators and their accessories, switchgear, protective devices, power transformers, converters, towers, conductors, regulating devices, and data gathering and computer control systems are analyzed. Inspections of nearby station equipment are planned to supplement classroom work. Mr. Zimmerman.

4444. HIGH VOLTAGE PHENOMENA (u,g)

Credit 3 hrs. Spring. Prerequisite, 4302. The study of problems of the normal operation of power systems at very high voltages, of the abnormal conditions imposed by lightning, of the methods employed to assure proper operation of power systems and apparatus under high-voltage conditions, and of the devices available for laboratory testing of equipment under actual or simulated conditions. An invitation to visit electrical manufacturing test facilities is usually accepted. Considerable attention is given to dielectric behavior and testing techniques. Mr. Zimmerman.

4445–4446. ELECTRIC ENERGY SYSTEMS I AND II (u,g)

Credit 4 hrs. per term. 3 Lect.-Rec.-Comp. Prerequisites, 4422 or 4302 and consent of instructor. The physical and engineering principles underlying steady-state and transient 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, high-voltage-direct-current systems, 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, fault, transient stability, and economic-analysis studies. Laboratory-computing periods will include selected experiments with electromechanical energy converters. At the level of Stevenson, *Elements of Power System Analysis* (2nd ed.). Mr. Linke.

RADIO AND PLASMA PHYSICS

[4461. WAVE PHENOMENA IN THE ATMOSPHERE (u,g)]

Credit 3 hrs. Fall. 3 Lect.-Rec. Prerequisites, 4302, 4312. 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. Not offered in 1968–69.

[4462. RADIO ENGINEERING (u,g)]

Credit 3 hrs. Spring. 3 Lect.-Rec. Prerequisites, 4312, 4401. 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. Not offered in 1968–69.

4464. ELEMENTARY PLASMA PHYSICS AND GAS DISCHARGES (u,g)

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisite, 4312 or equivalent. A review of electromagnetic wave theory. Plasma as a dielectric medium, plasma oscillations and waves, interaction of electromagnetic waves with a plasma, gas discharges, positive column, plasma sheath, Langmuir probes, collisions, magnetohydrodynamics, MHD generator. Laboratory work will include experiments with microwave circuits, gas discharges, lasers and application of measurement techniques to laboratory plasmas. Messrs. Nation and Wharton.

4551–4552. UPPER ATMOSPHERE PHYSICS I AND II (u,g)

Credit 3 hrs. each term. Fall and spring. 3 Lect. Prerequisite, 4312 or equivalent. The physical processes governing the behavior of the earth's ionosphere and magnetosphere will be considered. Topics covered will include the 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; the interaction between the magnetosphere and the solar wind; the acceleration and drift of energetic particles in the magnetosphere; the precipitation of particles and the aurora; magnetic and ionospheric storms. Mr. Farley.

4561. INTRODUCTION TO PLASMA PHYSICS (u,g)

Credit 3 hrs. Fall. 3 Lect. Prerequisites, 4311, 4312 or equivalent. Open to fourth-year students at discretion of instructor. 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 Longmire, *Elementary Plasma Physics*. Mr. Sudan.

4562. WAVES IN PLASMAS (u,g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4561. Magnetoactive cold plasma theory, CMA diagrams, plasma and cyclotron waves, whistlers, hydromagnetic waves, bounded plasmas, shocks, radiation; applications to laboratory and natural phenomena. At the level of Stix, *Theory of Plasma Waves*. Mr. Nation.

4564. ADVANCED PLASMA PHYSICS (u,g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4561. 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, etc., effects of collisions and Fokker-Planck terms; high frequency conductivity and fluctuations, quasi-linear theory; nonlinear wave interaction, weak turbulence and turbulent diffusion. Mr. Sudan.

4565–4566. RADIOWAVE PROPAGATION I AND II (g)

Credit 3 hrs. each term. Fall and spring. 3 Lect. Prerequisites, 4312 and 4401 or equivalent. Propagation in the earth's environment: the troposphere, ionosphere, magnetosphere, and interplanetary space. Topics covered will include 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, and full wave solutions; 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. Mr. Brice.

4661. KINETIC EQUATIONS (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, Physics 561, 562 or permission of instructor. Designed for students wishing a firm foundation in fluid dynamics, plasma kinetic theory, and nonequilibrium statistical mechanics. Brief review of classical 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. Equilibrium prescription of the approach to equilibrium. Coarse graining and ergodic theory. At the level of Prigogine, *Nonequilibrium Statistical Mechanics*. Mr. Liboff.

COMMUNICATIONS

4472. INTRODUCTION TO ALGEBRAIC CODING (u,g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, Mathematics 293 or equivalent. Intended for students interested in information theory or digital systems. Codes for correcting errors in data transmission or processing: Group codes, Hamming codes, Bose-Chaudhuri codes. Bounds on performance. Codes for data compression and storage: Variable-length codes, prefix codes. Codes for synchronization and their application to location of distant objects by radar. Analysis of these codes in terms of the underlying algebraic theory. Implementation by sequential machines. The algebraic theory (groups, fields, etc.) will be developed as needed. Mr. Sloane.

[4673. PRINCIPLES OF ANALOG AND DIGITAL COMMUNICATION (g)]

Credit 4 hrs. Fall. 3 Lect. Prerequisite, 4508 or consent of instructor. The course uses the fundamentals of information theory, signal theory, and statistical estimation and decision theory to formulate approaches to the solution of problems arising in digital and analog communication. Particular topcs 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 Viterbi, *Principles of Coherent Communication.* Not offered 1968–69.

4674. TRANSMISSION OF INFORMATION (g)

Credit 4 hrs. Fall. 3 Lect. Prerequisite, 4507 or Mathematics 571 or consent of instructor. A course applying 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 F. Jelinek, *Probabilistic Information Theory.* Mr. Berger.

[4676. DECISION AND ESTIMATION THEORY FOR SIGNAL PROCESSING (g)]

Credit 4 hrs. Fall. 3 Lect. Prerequisite, at least coregistration in 4507 or Mathematics 571. 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. Not offered in 1968–69.

COMPUTING SYSTEMS AND CONTROL

4481–4482. FEEDBACK CONTROL SYSTEMS (u,g)

Credit 4 hrs. Fall and spring. Prerequisite, 4302 or consent of instructor. Principles of feedback control systems with emphasis on methods of analysis and synthesis to meet prescribed performance criteria. One-sided Laplace transform applications; electronic, electromechanical, electrohydraulic, and pneumatic components; cascade and feedback compensation of linear control systems. Common physical nonlinearities encountered in control systems; phase plane and describing function; nonlinear compensation; dual mode systems; relay control systems. Z-transform; analysis of sampled data systems; digital compensation; optimization of sampled data systems. Laboratory work consists of experiments in: components, transient and frequency response measurements; compensation on linear and nonlinear control systems; simulation, design and optimization of control systems by analog and digital computers; projects of the student's choice. At the level of D'Azzo and Houpis, *Control System Analysis and Synthesis.* Mr. Curry.

4483. ANALOG COMPUTATION (u,g)

Credit 4 hrs. Fall. 2 Lect., 1 Lab. Prerequisites, concurrent registration in 4401 or an equivalent background with consent of the instructor. 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. Course develops fundamental ideas to include subjects at the level of Levine, *Methods of Solving Engineering Problems Using Analog Computers.* Mr. Vrana.

4484. ANALOG-HYBRID COMPUTATION (u,g)

Credit 3 or 4 hrs. by permission of instructor. Spring. 2 Lect., 1 Lab. Prerequisite, 4483. Theory, design, characteristics and programming of analog-oriented hybrid computer systems; analog-digital computer linkage components; error analysis and error compensation in hybrid computation; theory and laboratory work on analog iterative procedures, boundary value problems, optimization and random search. The laboratory work will make use of an analog computer linked with digital logic components. Mr. Vrana.

4487–88. SWITCHING THEORY AND SYSTEMS (g)

Credit 3 or 4 hrs. per term (4 hrs. with laboratory). Fall and spring. 3 Lect., 1 Lab. Prerequisite, Mathematics 293–294 or equivalent. First term prerequisite to second. 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. Mr. Torng.

4505–4506. OPTIMIZATION AND APPROXIMATION TECHNIQUES I AND II (g)

Credit 4 hrs. Fall and spring. 3 Lect. Prerequisites, 4402 and current registration in 4503 or consent of instructor. Optimization and 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. Optimum pole positions for exponential approximation. Computational methods for parameter optimization and approximation problems. 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. Statistical optimization problems. Synthesis of optimal filters and feedback controllers. Mr. Merriam.

4588. BIONICS AND ROBOTS (Theoretical and Applied Mechanics 1157) (u,g)

Credit 3 hrs. Fall. 3 Lect. Prerequisites, elementary differential equations, linear algebra and probability, or consent of instructor. Engineering applications of strategies and tactics of biological systems. Machines that learn. Artificial intelligence. Cybernetics, information and adaptive control. Reliable systems from unreliable components. Self-organizing systems. Features in patterns. Neural nets, perceptrons, threshold logic, madelines. Brain models. Behavior models. Machines for proving theorems, playing games, navigating, exploring. Problems of sensors, perception, recognition and recall. Problems of machines learning concepts, English, natural environments. Machine translation. Heuristic programming. Automata, pure and applied. Robots, hardware and software. Self-reproducing and self-repairing machines; models for embryology, development and evolution. Introduction to algebraic linguistics, Turing machines, and computability, Godel's theorem, the Euler-Diderot Metatheorem. Mr. Block.

4681. RANDOM PROCESSES IN CONTROL SYSTEMS (g)

Credit 4 hrs. Spring. 3 Lect. Prerequisites, 4508 and 4506. Prediction and filtering in linear control systems; Gaussian-Markov sequence, Gaussian-Markov process, prediction problem, Hamiltonian formulation of filtering problem, generalized Wiener filtering, stochastic optimal and adaptative 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; Gaussian input describing function, stability of control systems with random parameters. Mr. Thorp.

GENERAL

4591–4592. PROJECT (u,g)

Credit 3 hrs. Fall and spring. 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)

Credit 4 hrs. Fall. 3 Lect., 1 Lab. For first year graduate students and qualified seniors. 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 Kinsler and Frey, *Fundamentals of Acoustics*. Mr. Ingalls.

4595–4596. ELECTRICAL ENGINEERING DESIGN (g)

Credit 3 hrs. per term. Offered for students enrolled in the M. Eng. (E.) Program. A course utilizing real engineering situations in which to present fundamentals of engineering design.

4700–4800. SPECIAL TOPICS IN ELECTRICAL ENGINEERING (g)

Credit 1 to 3 hrs. Seminar, reading course, or other special arrangement agreed upon between the students and faculty members concerned.

Courses for Other Engineering Curricula

4921–4922. ELECTRICAL ENGINEERING LABORATORY (u)

Credit 1 hr. each term. 1 Lab. An introduction to electrical and electronic instrumentation, high-vacuum and solid-state devices, analog computation, and switching circuits.

4941–4942. INTRODUCTORY ELECTRICAL ENGINEERING (u)

Credit 3 hrs. per term. 2 Lect., 1 Rec.-Comp. Prerequisites, Mathematics 192, Physics 122 and at least coregistration in Mathematics 293 and Physics 223.

This sequence provides an introduction to the two broad interrelated areas of systems and electrophysics in electrical engineering. The four major topic areas of circuits, electronics, control systems, and electromechanics are treated throughout the year 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 advanced topics beyond the scope of the sequence. Some specific devices considered are transformers, tubes, transistors, volt and ammeters, motors, and generators. At the level of Fitzgerald, Higginbotham, and Grabel, *Basic Electrical Engineering.*

Courses for Other Curricula

4110. AN INTRODUCTION TO COMPUTER TECHNOLOGY (u)
Credit 3 hrs. Fall. 2 Lect., 1 Lab. A course for freshmen and sophomores with little or no background in technology. Concurrent registration in calculus desirable but not required. Covers in some detail the underlying technology of digital and analog computers, their component parts, organization, application, and impact on various aspects of society. In the laboratory sessions, readily understood devices are assembled to perform many simple tasks of the sort required in a computer. Includes lectures and exercises on the use of CUPL, a digital-computer programming language employed on this campus with the IBM 360. Mr. Bryant.

ENGINEERING PHYSICS

(For descriptions of courses see the section *Applied Physics.*)

ENVIRONMENTAL SYSTEMS ENGINEERING

(see page 115.)

GEOTECHNICAL ENGINEERING

(see page 118.)

INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

Service Courses

[9110. INTRODUCTORY INDUSTRIAL ENGINEERING (u)]
Credit 3 hrs. Spring. 2 Rec., 1 Lab.-Comp. Prerequisite, 9170. An introduction to modern industrial engineering with emphasis on the design activities of industrial engineers in specifying workplaces into integrated man-machine activity in such systems. Queuing theory, line balancing, and introductory concepts of linear programming will be presented as analytical

methods to be used in the analysis of plant design problems. Laboratory work and computing problems will be drawn from situations of interest to chemical, mechanical, electrical, and civil engineers. Not offered 1968–69.

9114. CONSUMER PRODUCTS ENGINEERING (Same as Chem. Eng. 5790) (g)

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Open to qualified seniors and M.Eng. students. 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.

9170. INTRODUCTORY ENGINEERING STATISTICS (u)

Credit 3 hrs. Both terms. 2 Rec., 1 Comp. Prerequisite, Mathematics 294 or equivalent. Applications of probability theory and statistics to industrial and engineering problems; point and confidence interval estimation; statistical testing of hypothesis; properties of binomial, Poisson, and hypergeometric distributions, and applications to sampling inspection problems; large sample theory and the normal distribution, small sample theory and Student's t and Chi-square distributions; introduction to correlation theory and curve fitting by least squares.

Required Courses

9301. INTRODUCTION TO INDUSTRIAL ENGINEERING (u)

Credit 3 hrs. Fall. 2 Lect., 1 Rec. An introduction to industrial engineering with emphasis on the changing character of modern industrial engineering practice. The work of the early industrial engineers will be studied, and the impact of the developing science of operations on design methodology associated with the engineering of complex man-machine systems will be reviewed. The relationship of systems engineering, industrial engineering, administrative engineering, management engineering, operations engineering, operations analysis, operations research, and management science will be discussed. Typical problems of interest to present-day industrial engineers and researchers will also be discussed to demonstrate the range of interest and application of industrial engineering methodology.

9303. INDUSTRIAL ENGINEERING LABORATORY (u)

Credit 4 hrs. Spring. 2 Lect., 2 Lab. Emphasis will be placed on the development of the scientific method as it relates to industrial engineering situations. Problem definition, development of hypotheses, and experimentation will be discussed with relevant techniques of measurement, estimation, design of experiments, prediction, and performance evaluation.

9310. INDUSTRIAL ENGINEERING ANALYSIS (u)

Credit 4 hrs. Fall. 3 Lect., 1 Comp. Prerequisites, 9350 and 9370, or equivalent. The application of cost, probability, and statistical theories in the analysis and evaluation of data typical to industrial engineering and operations research. Among the topics included are process capability studies; tests for statistical control; industrial sampling inspection procedures; statistical techniques in life and reliability analysis; engineering economic analysis for investment and replacement; work measurement; and probabilistic methods in inventory planning.

9320. DETERMINISTIC MODELS IN IE AND OR (u,g)

Credit 4 hrs. Fall. 3 Lect.-Rec., 1 Comp. Prerequisite, 9350. Mathematics 295. Analytical techniques for the solution of design, planning, and operational problems. Linear programming and the simplex method; transportation problem and assignment problems as special cases; the dual and its interpretation; the quadratic assignment problem. Flows in networks and flow algorithms; application to the transportation problem. Practical application of these techniques to make-buy decisions, product mix problems, facility allocation, machine grouping, routing of materials handling equipment, raw material blending, and general operational planning problems.

9321. PROBABILISTIC MODELS IN IE AND OR (u,g)

Credit 4 hrs. Spring. 3 Rec., 1 Comp. Prerequisite, 9360 or equivalent. 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 queueing 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)

Credit 4 hrs. Spring. 3 Lec.-Rec., 1 Comp. 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)

Credit 4 hrs. Fall. 3 Lect.-Rec., 1 Comp. Prerequisite, Mathematics 294 or equivalent. 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)

Credit 4 hrs. Spring. 3 Lect.-Rec., 1 Comp. Prerequisite, 9360. The application of statistical theory to problems associated with the analysis of data and inferences drawn therefrom. Principles of statistical inference: estimating the value of unknown parameters of probability distributions, testing hypotheses concerning these parameters; elements of statistical decision theory. Introduction to correlation theory and curve fitting by least squares. Applications in regression, statistical control, and experimentation.

9381. INTRODUCTION TO COMPUTER SCIENCE (u)

Credit 4 hrs. Fall. 2 Lect., 1 Rec.-Comp. Introduction to the field of computer sciences including principles and characteristics of information processing equipment, programming languages, and applications. Topics are selected to illustrate a wide range of current and potential areas of application with emphasis being placed on the modern digital computer as a symbol-manipulating device rather than as an arithmetic calculator. Number systems, computer logic and organization, and characteristics of current equipment are covered along with various aspects of programming. Also, introductory concepts and problems associated with using computers in information processing systems, real-time control systems, simulated experimentation, and the design process are considered.

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)

Credit 4 hrs. Fall. 3 Lec.-Rec., 1 Comp. This course covers the same topics as 9360 described above, but all lectures and computings are independent of those for 9360.

9470. INTRODUCTION TO STATISTICAL THEORY WITH ENGINEERING APPLICATIONS (u,g)

Credit 4 hrs. Spring. 3 Lect., 1 Rec.-Comp. Prerequisite, 9360 or 9460. This course covers the same topics as 9370 described above, but all lectures and computings are independent of those for 9370.

9481. INTRODUCTION TO COMPUTER SCIENCE (Comp. Sc. 401) (u,g)

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. This course covers the same topics as 9381 described above.

Elective and Graduate Courses

9501. ENGINEERING ADMINISTRATION (g)

Credit 3 hrs. Spring. 3 Lect.-Rec. Prerequisite, graduate standing. Organization of the engineering function, planning and analysis of engineering activities. Project management and control. Problems of innovation and introducing technological change. Measurement and evaluation of engineering activities. Selected topics from current literature.

[9511. MANUFACTURING ENGINEERING (g)]

Credit 3 hrs. Fall. 1 Lect., 1 Rec.-Comp. Intended for graduates or qualified undergraduates. Prerequisite, 9311. The analysis and design of production facilities based on output requirements of the system. Attention will be directed towards the interaction of processing methods and requirements with handling methods and storage facilities. The effects of various levels of mechanization on operating costs and initial investment will be studied. Not offered 1968–69.

9512. STATISTICAL METHODS IN QUALITY AND RELIABILITY CONTROL (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 9370 or equivalent. Control concepts: control chart methods for attributes and for 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)]

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Elective for graduate students and qualified undergraduates. Prerequisite, 9320 and 9370 or permission of instructor. 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. Not offered 1968–69.

9521. PRODUCTION PLANNING AND CONTROL (g)

Credit 4 hrs. Spring. 3 Lect.-Rec., 1 Comp. Prerequisites, 9320 and 9321, or permission of instructor. 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)

Credit 3 hrs. Fall. 3 Lect.-Rec. Prerequisite, permission of the instructor. Not open to students who have had 9320. Model design, methodology of operations research, linear programming, transportation problem, assignment problem, dual theorem, parametric linear programming, integer programming, non-linear programming, dynamic programming, introduction to inventory theory; comprehensive problems and case studies.

9523. OPERATIONS RESEARCH II (g)

Credit 3 hrs. Spring. 3 Lect.-Rec. Prerequisite, 9360, 9170, or permission of the instructor. Not open to students who have had 9526. Models for inventory and production control; replacement theory; queuing including standard birth and death process model and non-standard models, application of queuing theory; simulation; game theory, illustrative examples and problems.

[9524. PROBLEMS IN OPERATIONS RESEARCH (g)]

Credit 3 hrs. One 2-hr. meeting weekly. Prerequisite, 9523 or equivalent. An advanced seminar concentrating on problem definition, measures of effectiveness, applicability of various analytical methods to the solution of real problems. Not offered in 1968–69.

[9525. FLOW AND SCHEDULING IN NETWORKS (g)]

Credit 3 hrs. Spring. 3 Lect.-Rec. 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. Not offered in 1968–69.

9526. MATHEMATICAL MODELS–DEVELOPMENT AND APPLICATION (g)

Credit 4 hrs. Fall. 3 Lect.-Rec., 1 Comp. Prerequisite, 9320 and 9321, or equivalent. Examination of relevant probabilistic and deterministic models 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. Model testing, validation, and sensitivity will be discussed.

9529. PROBLEMS AND TECHNIQUES IN OPTIMIZATION (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 9360 and 9320. The application of a variety of operations research techniques and analytical skills in actual situations. Lectures on enumeration methods as found in branch and bound techniques, discrete dynamic programming, column generation methods, linear programming, quadratic assignment techniques, combinatorial analysis and graph theoretic techniques, and networks including techniques for handling problems of uncertainty. Problems will include multidimensional trim problems, networks and scheduling problems, maintenance problems, routing problems, selection problems, fixed charge problems, location problems, and special problems in optimal design of production and distribution systems within the context of a vertically integrated firm.

9530. MATHEMATICAL PROGRAMMING I (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisites, Mathematics 331, Mathematics 411 or 9320, or permission of the instructor. 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)]

Credit 3 hrs. Fall. 3 Lect.-Rec. Prerequisite, 9530. Complementary pivot theory. Semi-infinite programming and duality in convex programming. Computational algorithms. Integer programming. Chance-constrained programming and piecewise linear decision rules. Combinatorial analysis and extremal methods. Not offered in 1968–69.

[9533. GRAPH THEORY AND COMBINATORIAL ANALYSIS (g)]

Credit 3 hrs. Fall. 3 Lect.-Rec. Prerequisite, permission of the instructor. Finite, infinite, directed, undirected, combinatorial, and topological graphs. Connectedness, planarity, coloring and matching problems, matrix methods, network problems. Applications to electrical networks, economics, and sociometry. Incidence systems such as finite geometrics and block designs. Matrices of zeros and ones, perfect difference sets, Latin squares. Combinatorial extremum problems. Not offered in 1968–69.

9535. GAME THEORY (g)

Credit 3 hrs. Fall. 3 Lect.-Rec. Prerequisite, permission of the instructor. 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)

Credit 3 hrs. Spring. 3 Lect.-Rec. Prerequisite, 9560. 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)]

Credit 3 hrs. Spring. 3 Lect.-Rec. Prerequisite, 9532. Topics chosen from current research areas such as integer programming over finitely generated groups, chance-constrained games, duality theory, infinite games. Not offered in 1968–69.

9550. ENGINEERING ECONOMIC ANALYSIS (g)

Credit 3 hrs. Fall. 3 Lect. 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)

Credit 4 hrs. Spring. 3 Lect. Prerequisite, 9311 or equivalent. 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)

Credit 4 hrs. Spring. 3 Lect., 1 Rec. Open to qualified undergraduates. Prerequisites, 9360 and 9370, or permission. An introduction to stochastic processes, emphasizing basic theory and its engineering application. The following topics are covered: second order processes; covariance function and spectral distribution; Markov chains and processes; diffusion processes; renewal theory and recurrent events; fluctuation theory; random walks, branching processes, queues, Brownian motion, and birth and death processes.

9561. QUEUING THEORY (g)

Credit 3 hrs. Fall. 2 Rec., 1 Comp. Prerequisites, 9360 and permission of the instructor. 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)

Credit 3 hrs. Spring. 3 Lect.-Rec. Prerequisites, 9321 and permission of the instructor. 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; multi-echelon problems; statistical problems; and production smoothing. Not offered 1968–69.

[9563. SELECTED TOPICS IN THE THEORY OF QUALITY AND RELIABILITY CONTROL (g)]

Credit 3 hrs. Spring. 3 Lect. Open to qualified undergraduates. Prerequisite, 9370 or the equivalent. The statistical properties and derivation of some quality and reliability control procedures. Topics will include the economic design of Shewhart control charts, cumulative sum control charts, Girshick and Rubin control procedures, moving average control charts, sampling inspection by variables for percent defective, reliability estimation, and reliability growth models. Not offered in 1968–69.

[9564. SEQUENTIAL DECISION AND CONTROL PROCESS (g)]

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 9537. Concentration on Markov sequential decision models with general action and state species. A careful study of the underlying probabilistic structure. Finite horizon problems, total expected discounted return, optimal stopping, time average return criteria. Study of the existence and characterization of optimal control strategies. Not offered in 1968–69.

9565. TIME SERIES ANALYSIS (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, permission of the instructor. Introduction to Hilbert space and its application to linear regression, linear prediction and estimation, and spectral analysis. Properties of martingales with application to prediction and discrimination.

9569. SELECTED TOPICS IN APPLIED PROBABILITY (g)

Credit 3 hrs. Either term. 3 Lect. Prerequisites, 9560 and permission of the instructor. Selected topics in applied probability for advanced students. Topics will be selected from current literature and from the current research areas of the staff.

9570. INTERMEDIATE ENGINEERING STATISTICS (g)

Credit 3 hrs. Fall. 2 Rec., 1 Comp. Prerequisite, 9370, 9470 or permission of the instructor. Application of statistical methods to the efficient design, analysis, and interpretation of industrial and engineering experiments; rational choice of sample size for various statistical decision procedures and the operating characteristic curves of these procedures; curve fitting by least squares; simple, partial, and multiple-correlation analysis.

9571. DESIGN OF EXPERIMENTS (g)

Credit 4 hrs. Fall. 2 Rec., 1 Comp. Prerequisite, 9570 or permission of the instructor. 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)]

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 9370, 9570, or equivalent. 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. Not offered in 1968–69.

9573. STATISTICAL MULTIPLE DECISION PROCEDURES (g)

Credit 3 hrs. Spring. 2 Rec., 1 Comp. Prerequisite, 9571 or permission of the instructor. 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.

9579. SELECTED TOPICS IN STATISTICS (g)

Credit 3 hrs. Either term. 2 Rec., 1 Comp. Prerequisite, 9570 or permission of the instructor. Selected topics chosen from such fields as nonparametric statistical methods, sequential analysis, multivariate analysis.

9580. DIGITAL SYSTEMS SIMULATION (g)

Credit 4 hrs. Fall. 2 Lect., 1 Rec. Required of M.Eng. (Ind.) students. Prerequisites, 9381 and 9370, or permission of the instructor. 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)

Credit 4 hrs. Spring. 2 Lect., 1 Comp. Prerequisite, 9381 or permission of the instructor. 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.

9590. SPECIAL INVESTIGATIONS IN INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH (u,g)

Credit and sessions as arranged. Either term. 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)

Credit 1 hr. Both terms. A weekly 1½-hr. meeting. A weekly 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 (FALL TERM), 9594 (SPRING TERM), INDUSTRIAL ENGINEERING GRADUATE SEMINAR (g)

Credit 1 hr. each term. A weekly meeting to discuss assigned topics and to hear presentations of the current "state of the art" from practitioners in the Field.

9598 (FALL TERM), 9599 (SPRING TERM), PROJECT (g)

Variable credit. A normal requirement of 8 credit hrs. must be completed by each candidate for a professional Master's degree, during the last two terms of matriculation. 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.

MACHINE DESIGN AND MATERIALS PROCESSING

(se page 162.)

MATERIALS SCIENCE AND ENGINEERING

6031. STRUCTURE OF MATERIALS I (MATERIALS SCIENCE I) (u)

Credit 3 hrs. Fall. 3 Lect.-Rec. Prerequisite, 6211. Properties of crystalline matter discussed in terms of the spacial arrangement of atoms. The influence of defects and microstructure on physical properties.

6032. MECHANICAL PROPERTIES OF MATERIALS (MATERIALS SCIENCE II) (u)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 6211. Elastic, plastic, and fracture phenomena in solids, including yielding, strain hardening, brittle fracture, creep and fatigue.

6033. STRUCTURE OF MATERIALS II (MATERIALS SCIENCE I) (u)

Credit 2 hrs. Fall. 3 Lect.-Rec. Prerequisite, 6211. Internal and external symmetry of crystals. Fresnel and Fraunhofer diffraction. Resolution of optical instruments. Gratings. Optical and phase contrast microscopy, interferemetry, electron and x ray diffraction. Reciprocal lattice. Production of x rays, electrons and neutrons, x ray techniques. Intensity calculations.

6034. STRUCTURE OF MATERIALS LABORATORY (u)

Credit 2 hrs. Spring. Lab. Experiments designed to demonstrate basic techniques in crystallography. X ray diffraction, optical metallography, electron transmission metallography and quantitative metallography.

6035. THERMODYNAMICS AND FLUID MECHANICS (u)

Credit 3 hrs. Fall. 3 Lect. Introduction to classical thermodynamics, kinetic theory of gases and statistical mechanics. Application to engineering problems.

6036. THERMODYNAMICS OF CONDENSED SYSTEMS (u)

Credit 3 hrs. Spring. 3 Lect. 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. At the level of R. A. Swalin, *Thermodynamics of Solids;* G. S. Rushbrooke, *Introduction to Statistical Mechanics.*

6041. KINETICS (MATERIALS SCIENCE III) (u)

Credit 3 hrs. Fall. 3 Lect. 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 (MATERIALS SCIENCE IV) (u)

Credit 3 hrs. Spring. 3 Lect. 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 super-conducting materials.

6043–6044. SENIOR MATERIALS LABORATORY (u)

Credit 3 hrs. Fall or spring. Experiments are available in the areas of structural studies, properties of materials, deformation and plasticity, mechanical and chemical processing, phase transformations, surface physics, etc.

6045. MATERIALS PROCESSING I (MECHANICAL) (u)

Credit 3 hrs. Fall. 3 Lect. A course relating 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 variation in processing is emphasized. Processing methods considered include solidification, deformation, heat treatment, material bonding, material removal, consolidation of powders, and others.

6046. MATERIALS PROCESSING II (CHEMICAL) (u)

Credit 3 hrs. Spring. 3 Lect. 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)

Credit 3 hrs. Fall or spring. 2 Lect., 1 Lab., 1 Rec. alternate weeks. An introduction to the basic concepts of materials science.

1. Structure: Structure of gases, liquids and solids, atomic binding, observations of structure by x ray diffraction, packing concepts and crystalline defects, microstructures.
2. Thermodynamics and Equilibrium: Laws of thermodynamics; chemical and physical reactions; phase equilibria, electrochemical systems, thermodynamical and statistical mechanical models of solutions, equilibrium defects, surfaces.
3. Kinetics: Reaction rates in gases and condensed systems; atomic and ionic transport processes; kinetics of phase transformation.
4. Properties: Mechanical, electrical, and magnetic properties of materials with emphasis on structure-sensitive properties.

6316. MATERIALS ENGINEERING (u)

Credit 3 hrs. Fall. 2 Lect., 1 Lab. 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 is emphasized. Processing methods considered involve solidification, plastic deformation, heat treatment, material bonding, and consolidation of powders.

Graduate Core Program: Materials Science and Engineering

6601. TOPICS IN THERMODYNAMICS AND KINETICS (g)

Credit 3 hrs. Fall. 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 Slater, *Introduction to Chemical Physics;* Guggenheim, *Thermodynamics.*

6602. PHASE TRANSFORMATIONS (g)

Credit 3 hrs. Spring. 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 Christian, *Theory of Phase Transformations in Metals and Alloys.*

6603. CRYSTAL MECHANICS (g)

Credit 3 hrs. Fall. 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. Thermo-physical properties. Irreversible tensor properties. Coupling of transport phenomena. Higher order effects. At the level of Nye, *Physical Properties of Crystals;* Born and Huang, *Dynamical Theory of Crystal Lattices;* and Smith, *Wave Mechanics of Crystalline Solids.*

6604. DISLOCATIONS (g)

Credit 3 hrs. Fall. 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 Friedel, *Dislocations* and Nabarro, *Theory of Crystal Dislocations.*

6605. ELECTRICAL AND MAGNETIC PROPERTIES OF ENGINEERING MATERIALS (g)

Credit 3 hrs. Fall. Prerequisite, 454 or consent of the instructor. Electrical properties of semiconductors. Optical and dielectric properties of insulators and semiconductors. Ferrites. At the level of Kittel, *Introduction to Solid State Physics;* Chikazumi, *Physics of Magnetism;* Lynton, *Superconductivity;* Livington and Schadler, *The Effect of Metallurgical Variables on Superconductivity Properties.*

6606. MECHANICAL BEHAVIOR OF MATERIALS (g)

Credit 3 hrs. Spring. Strain hardening. Dislocation dynamical treatment of yield and flow. Polycrystalline hardening. Interaction of interstitial solute atoms with dislocations. Solution hardening. Two-phase hardening. Time dependent deformation. Dislocation models for cleavage of crystals. At the level of review articles in *Progress in Materials Science* and various conference reports.

6611. PRINCIPLES OF DIFFRACTION (g)

Credit 3 hrs. Fall. 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 as well as 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.

For the Professional Master's Degree

[6503. METALS SELECTION AND USE (g)]

Credit 3 hrs. Fall. 3 Lect. 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. Not offered 1968–69.

6553–6554. PROJECT (g)

Credit 6 hrs. Fall and spring. Research on a specific problem in materials or metallurgical engineering.

6555. MATERIALS PROCESSING (g)

Credit 3 hrs. Spring. 3 Lect. A course on 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 practice are stressed.

Other Graduate Courses

6612. SELECTED TOPICS IN DIFFRACTION (g)

Credit 3 hrs. Spring. 3 Lect. 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.

6762. PHYSICS OF SOLID SURFACES (g)

Credit 3 hrs. Spring. 3 Lect. 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 such as *Progress in Materials Science*.

Advances in Chemistry, Solid State Physics; and specialized texts such as Many, Goldstein and Grover, *Semiconductor Surfaces,* and Kaminsky, *Atomic and Ionic Impact Phenomena.*

6764. FRACTURE OF MATERIALS (g)

Credit 3 hrs. 3 Lect. 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; Tetelman and McEvily, *Fracture of Structural Materials;* Kelly, *Strong Solids.*

6765. AMORPHOUS AND SEMICRYSTALLINE MATERIALS (g)

Credit 3 hrs. 3 Lect. 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 J. D. Mackenzie, *Modern Aspects of the Vitreous State;* Frechette, *Non-crystalline Solids;* Treloar, *The Physics of Rubberlike Elasticity.*

6766. MATERIALS SCIENCE SEMINAR (g)

Credit 2 hrs. One seminar period. Topics selected from current research interest of the faculty.

6873. MATERIALS SCIENCE FOR ENGINEERS (g)

Credit 3 hrs. Fall. 3 Lect. 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, Engineering Design, Materials Processing,* and *Thermal Engineering.*

General

3053. MECHANICAL ENGINEERING LABORATORY (u)

Credit 4 hrs. Fall. 1 Lect., 2 Lab. Prerequisites, 3322, 3622, 3623, and simultaneous registration in 3324 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)

Credit 4 hrs. Spring. 2 Lect., 2 Design periods. Prerequisites, 3322, 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.

3055. ADVANCED MECHANICAL ENGINEERING DESIGN (g)

Credit 3 hrs. Spring. 1 Lect., 2 Design periods. Prerequisite, 3054 or equivalent. Design of engineering systems, components and equipment in the widest sense, requiring the integration of engineering disciplines at an advanced level.

3090. MECHANICAL ENGINEERING DESIGN PROJECT (g)

Credit 3 hrs. Spring. 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.

Engineering Design

See also Courses 3054, 3055, 3090 under *General* above.

3116. INTRODUCTION TO INDUSTRIAL DESIGN (u,g)

Credit 3 hrs. Spring. 2 Lab. Prerequisite, permission of the instructor. Readings; abstract and applied design problems which investigate and apply the relationships existing among form, function, and materials.

3321. KINEMATICS AND DYNAMICS OF MECHANICS (u)

Credit 3 hrs. Fall. 2 Rec., 1 Comp. Prerequisite, 212. Analysis of displacement, velocity, and acceleration in basic mechanisms for control, transmission, and conversion of motion and force. Cams, gears, and four-bar linkages. Forces associated with accelerated motion and gyroscopic action. The flywheel as a speed control device. Counter-balancing. (Evening preliminary examinations)

3322. ANALYSIS AND DESIGN OF MACHINE COMPONENTS (u)

Credit 3 hrs. Spring. 2 Rec., 1 Design period. Prerequisites, 3321, 6316, and 3431; 3431 may be taken concurrently. A study of some major components of mechanical equipment such as clutches, brakes, gears, shafts, and bearings, with particular attention to performance characteristics, strength and durability, optimum proportions, and choice of materials. Stress-concentration, fatigue, and residual stresses. Curved beams, pressure vessels, and rotors. (Evening preliminary examinations.)

3324. VIBRATION AND CONTROL OF MECHANICAL SYSTEMS (u)

Credit 3 hrs. Fall. 2 Rec., 1 Lab. Prerequisite, 3321 or 3331. 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.

3331. KINEMATICS AND COMPONENTS OF MACHINES (u)

Credit 3 hrs. Spring. 2 Lect.-Rec., 1 Comp. Prerequisite, 212 or equivalent. May be elected by qualified students not in mechanical engineering. Theory and analysis of mechanisms and components based upon 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)

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 3322 or 3331. Theory of film-lubricated bearings; advanced analysis of special friction devices; theories of failure and design equations; prestressing; impact; thermal stresses and creep; selected topics from advanced strength of materials such as built-up cylinders, rotors, plates, shells, beams on elastic foundations, etc.

3362. MECHANICAL DESIGN OF TURBOMACHINERY (g)

Credit 3 hrs. Spring. 3 Rec. Prerequisites, 3361 and 3324. Mechanical design of major components of high speed compressors and turbines for structural adequacy and vibration-free operation. Selected topics from among the following: design of rotor components: disks, vanes, blades, shafts, and connections. Design of bearings, seals, gaskets, expansion members. Investigation of natural frequencies and critical speeds. Selection of material.

3364. DESIGN FOR MANUFACTURE (u,g)

Credit 3 hrs. Fall. 2 Rec., 1 Design or Lab period. Prerequisites, 3322 or 3331, and 3431 or equivalent, or permission of the instructor. 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)

Credit 3 hrs. Fall. 2 Rec., 1 Comp. Prerequisite, 3321 or 3331. 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)

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Open to qualified undergraduates. Prerequisite, 3324 or equivalent. Further development of vibration phenomena in single- and multi-degree 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 and 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)

Credit 3 hrs. Fall. 1 Rec., 2 Lab. 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)

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 3322 or equivalent. Open to qualified undergraduates. Conception and initial design of products and machines. Methods to stimulate mechanical ingenuity and improve appearance. Principles of synthesis and creativity employing association, inversion, and other techniques. Sketching, class discussion, and comparative evaluation of solutions.

3375. AUTOMATIC MACHINERY (u)

Credit 3 hrs. Spring. 2 Rec., 1 Field trip. Prerequisite, 3321 or 3331. A study of automatic and semiautomatic machinery such as dairy, canning, wire-forming, textile, machine-tool, computing, and printing equipment.

3377. AUTOMOTIVE ENGINEERING (u)

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 3322. 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)

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Open to qualified undergraduates. Prerequisite, 3324 or equivalent. Further development of feedback control theory, including stability criteria, frequency response, and transfer functions, with emphasis on engineering problems involving the analysis of existing control systems and the design of systems to perform specified tasks. 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.

3380–3381. DESIGN OF COMPLEX SYSTEMS (g)

Credit 3 hrs. Fall and spring. Two meetings of 2 hours per week to be arranged. Permission of professor in charge. 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)

Credit 3 hrs. Spring. 3 Rec. 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. Central topics include equations of viscous flow in this 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.

3390. SPECIAL INVESTIGATIONS IN MACHINE DESIGN (u,g)

Permission of department head required. Credit arranged. Either term. Individual work or work in small groups under guidance in the design and development of a complete machine, in the analysis of experimental investigation of a machine or component of a machine, or studies in a special field of machine design.

3392. SPECIAL TOPICS IN ENGINEERING DESIGN (u,g)

Credit 1 hr. or more. Either term. 10–15 lecture periods per term on a topic of special interest not requiring a course of standard length. Series of lectures by staff members or visiting staff on subjects of current interest; topics announced prior to beginning of term. Hours to be arranged to suit. More than one topic may be taken if offered. Department to be consulted before registration.

Materials Processing

3431. MATERIALS PROCESSING (u)

Credit 3 hrs. Both terms. 1 Lect., 2 Lab. Comprehensive studies of materials and machinery involved in material removal. Force, deformation, and power relationships. Single, multiple, and multi-tooth tool capabilities. Ultrasonic, electrical discharge, electro-chemical, 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)

Credit 3 hrs. Fall. 1 Lect., 2 Lab. Prerequisites, 3431, 6316. 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 post-process treatments.

3461. QUALITY ASSURANCE SYSTEMS (u)

Credit 3 hrs. Either term by arrangement. 2 Lect., 1 Lab. Prerequisites, 3431, 9170. Theory and computational techniques for control by attributes or variables. Machine tool capability studies, instrumentation systems. Standards codes and applications. Equipment performance characteristics. Fixed and comparative gaging systems; noncontract, reflective, and radiation principles. Surface texture phenomena. True-position tolerancing and charting.

3475. NUMERICAL CONTROL OF PROCESSES (u,g)

Credit 3 hrs. Spring. 2 Lect., 1 Lab-Comp. Prerequisite, 3431. A thorough study of concepts, systems, and component designs for flexible-programmed processing. Machine tools as related to numerical control. Machine command-response factors, stick-slip, resonance, shaft windup, mass-inertia and other effects. Positioning control systems and coding. Manual and computer programming. Simulation studies.

3490. SPECIAL INVESTIGATIONS IN MATERIALS PROCESSING (u)

Credit and hours as arranged. Discussion and study of selected topics on theory of metal cutting and working processes, the technology of manufacture with machine tools, and metrology and production gaging; topics and assigned study to suit individual needs.

Thermal Engineering

3621. INTRODUCTION TO THERMODYNAMICS (u)

Credit 3 hrs. Fall. 3 Rec. Prerequisites, Mathematics 294, Physics 224. The definitions, concepts, and laws of classical thermodynamics. Applications to homogeneous systems and control volumes. Potential function, maximum work, availability, and irreversibility. Maxwell's relations and general thermodynamics functions. Entropy and thermodynamic probability. Ideal gases, gas processes, and variable specific heats.

3622. ENGINEERING THERMODYNAMICS (u)

Credit 2 hrs. Spring. 2 Rec. Prerequisite, 3621 or equivalent. Thermodynamic properties of multiphase pure substances and real gases. Nonreactive mixtures, reactive systems, combustion. Chemical equilibrium and chemical potential; applications to combustion. Heat engine and heat pump cycles. Introduction to irreversible thermodynamics; applications.

3623. FLUID MECHANICS (u)

Credit 4 hrs. Spring. 4 Rec. Prerequisites, Mechanics 212, 3621. Properties of fluids, fluid statics; kinematics of flow, stream function, velocity potential, elements of hydrodynamics; dynamics of flow, momentum and energy relations, Euler equations, wave motion; thermodynamics of flow, stagnation values, Mach number relationships; dimensional analysis; real fluid phenomena, laminar and turbulent motion; flow in ducts, universal velocity distribution; compressible flow with area change, friction and heating, normal shock; flow over immersed bodies, laminar and turbulent layer, exact and momentum solutions; lift and drag; elements of two-dimensional compressible flow, expansion waves, oblique shock.

3625. HEAT TRANSFER (u)

Credit 3 hrs. Fall. 1 Lect., 2 Rec. Prerequisites, 3622, 3623. Conduction of heat in the steady state, unsteady state and periodic heat flow; analogic methods; numerical methods; 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 exchanges: overall heat transfer coefficients; mean temperature difference; effectiveness; design.

3626. THERMAL SYSTEMS ENGINEERING (u)

Credit 4 hrs. Spring. 2 Lect., 1 Lab. Prerequisites, 3622, 3623, 3053, 3625. Applications of thermodynamics, fluid mechanics, and heat transfer to complete thermal systems rather than to processes. Work-producing, heat-producing, heat-pumping, propulsion, and environmental control systems. Steady state and transient system performance. Component matching.

3631. THERMODYNAMICS (u)

Credit 3 hrs. Fall. 2 Lect., 1 Rec. Prerequisites, Mathematics 294, Physics 224. Not open to students in mechanical engineering. The definition, laws, and concepts of classical thermodynamics. Applications to homogeneous systems and control volumes. Availability, equilibrium, and chemical thermodynamics. An introduction to microscopic descriptions, thermodynamic probability, and statistical mechanics.

3632. FLUID MECHANICS (u)

Credit 3 hrs. Spring. 2 Lect., 1 Rec. Prerequisite, 3631. Not open to students in mechanical engineering. Course emphasis is on the dynamics of real fluids, and approaches to be used in solving these problems. Treatment includes the finite control volume, differential equations of motion, and dynamic similitude. Applications are to problems of incompressible and compressible fluid flow, both inviscid and viscous.

3651. ADVANCED THERMAL SCIENCE (g)

Credit 3 hrs. Fall. 3 Rec. Prerequisites, 3622, 3623, 3625, or equivalent. Intended for graduate students in the M.Eng. (Mech.) program. Advanced-level study of topics from thermodynamics, fluid mechanics, and heat transfer. Selection of subjects from irreversible thermodynamics, statistical mechanics, real gas behavior, chemical thermodynamics, unsteady flow phenomena, gas dynamics, turbulent flow of jets and wakes, compressible boundary layer, numerical methods, and variable transport properties.

3652. COMBUSTION THEORY (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 3625. Open to qualified undergraduates. Application of the basic equations of fluid flow and heat and mass transfer to homogeneous and diffusion flames. Ignition, quenching, rate processes, and dissociation effects will be examined. Consideration will be given to flame stabilization and practical systems. Mr. McManus.

3653. REFRIGERATION (u)

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 3625 or 3625 concurrently. Introduction to refrigeration with emphasis on application of thermodynamics, fluid dynamics and heat transfer. Cycle and component performance. Applications in air conditioning and cold storage. Overall performance under varied operating conditions. Cryogenic refrigeration; gas liquefaction, purification, storage, and special heat transfer problems. Thermoelectric cooling. Mr. Fairchild.

3654. AIR CONDITIONING (u)

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 3625 or 3625 concurrently. Introduction to air conditioning with emphasis on application of thermodynamics, fluid dynamics, mass transfer and heat transfer. Psychrometrics, air conditioning processes and cycles. Heat transmission in buildings; solar effects; lumped thermal circuit methods. Heat pumps. Air distribution. Component and system performance. Mr. Fairchild.

3661. EQUILIBRIUM THERMODYNAMICS (g)

Credit 3 hrs. Fall. 3 Lect. Prerequisites, 3621 and 3622 or equivalent. Intended for graduate students but open to qualified undergraduates. A general treatment of classical or axiomatic thermodynamics with emphasis upon the mathematical developments and philosophical interpretations. Concepts and laws of thermodynamics and equivalence proofs. Homogeneous and pure substances, heterogeneous systems, and chemical thermodynamics. Equilibrium, irreversibility, and availability. The statistics of ensembles, classical and quantum statistics, and an introduction to information theory. The connections between the statistical and classical viewpoints. Mr. Conta.

[3663. TURBOMACHINERY (u,g)]

Credit 3 hrs. Fall. 3 Rec. Prerequisites, 3622, 3623, or permission of instructor. 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. Attention is drawn to 3362 as a companion course for mechanical design. Not offered 1968–69.

3665. TRANSPORT PROCESSES (u,g)

Credit 3 hrs. Fall. 3 Rec. Prerequisites, basic thermodynamics and fluid mechanics. Description of basic microscopic modes of thermal and mass diffusion. Molecular transport mechanics in gases. Formulation of the transport equations and their application to engineering problems. Conduction and mass diffusion in solids, boundary value problems. Thermal radiation between opaque surfaces in vacuum and as a diffusion process in nonopaque media. Mass and energy diffusion by molecular and by eddy processes in convection. Analytical methods in convection investigated, limits shown, and the role of correlations discussed. Analogous phenomena. Combined mode heat transfer. Mr. Gebhart.

3667. TECHNIQUES OF THERMAL MEASUREMENT (g)

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Open to qualified undergraduates. Prerequisite, 3625. Theory, construction, calibration, and application of liquid-in-glass thermometers, solid expansion thermometers, pressure-spring thermometers, resistance thermometers, thermoelectric thermometers, optical pyrometers, radiation pyrometers, enthalpy probes, heat flux probes. Mr. Dropkin.

3669. COMBUSTION ENGINES (u)

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 3625 or 3625 concurrently. Introduction to combustion engines with emphasis on application of thermodynamics, fluid dynamics, and heat transfer; reciprocating combustion engines; gas turbines; compound engines; reaction engines. Mr. Fairchild.

3670. ADVANCED COMBUSTION ENGINES (u)

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 3669 or equivalent. Advanced study of topics in field of reciprocating engines, both spark-ignition and diesel. Methods of thermodynamic analysis and performance prediction for free-piston power plants and supercharged engines. Relation of engine performance characteristics and performance characteristics of automotive vehicles. Recommended together with Course 3377 for study in automotive engineering. Mr. Fairchild.

3671. AEROSPACE PROPULSION SYSTEMS (u,g)

Credit 3 hrs. Fall. 3 Rec. Prerequisites, 3622, 3623, or permission of instructor. 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. Mr. Shepherd.

3672. ENERGY CONVERSION (g)

Credit 3 hrs. Spring. 3 Lect. Open to qualified undergraduates. Prerequisite, 3622 or equivalent. 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 some 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. Mr. Conta.

3673. ADVANCED FLOW MEASUREMENT (g)

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Open to qualified fifth year students. Theory and operation of instruments used in fluid flow investigations; hot wire anemometers; density-sensitive optical systems, transient temperature and pressure measurements; measurements in reacting systems; error analysis and treatment of data. Mr. McManus.

3674. STATISTICAL THERMODYNAMICS (g)

Credit 3 hrs. Spring. 3 Rec. Prerequisites, 3622, 3623 or equivalent. Intended for graduate students but open to qualified undergraduates. The statistical mechanical basis of the first and second laws of thermodynamics. The interrelationships between classical thermodynamics and the fields of classical, quantum, and statistical mechanics. The statistical mechanics of ideal and real gases, black body radiation, diatomic molecular systems, and fluctuations. Thermal considerations of molecular laser systems. Equilibrium in multicomponent systems. Mr. Cool.

3675. THEORETICAL FLUID MECHANICS I (g)

Credit 3 hrs. Fall. 3 Rec. Prerequisite, concurrent enrollment in 1180 or equivalent. Navier-Stokes equation and exact solutions. Vorticity theorems. Irrotational incompressible flow in two and three dimensions. Wing theory, slender body theory. Rotational flow including shear-induced secondary flows, effects of strong rotation or stratification, Ekman layers. Compressible flow in one dimension, wave equation, Riemann invariants. Shock waves. Mr. Leibovich.

3676. THEORETICAL FLUID MECHANICS II (g)

Credit 3 hrs. Spring. 3 Rec. A continuation of 3675. Effects of viscosity including exact solutions, boundary-layer theory and calculation methods; similarity solutions; displacement effects; wake flows; dissipation of sound waves and weak-shock structure. Stability of laminar flows and elements of turbulence theory. Supersonic and hypersonic flow fields. Two-phase flow. Mr. Moore.

3680. ADVANCED CONVECTION HEAT TRANSFER (g)

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 3665 or consent of instructor. Processes of transport of thermal energy, momentum, and mass in fluids are considered in detail. Theories of transfer processes and analytic solutions. Analytical and experimental results compared. Transport equations for a fluid, delineation of kinds of processes, differential similarity, natural convection, forced convection at low and high velocities. Boundary layer solutions, similarity theories, and effects of turbulence. Transport in rarefied gases. Mr. Gebhart.

3681. NONEQUILIBRIUM FLOW AND RADIATIVE TRANSFER (g)

Credit 3 hrs. Fall. 3 Rec. Prerequisites, 3674 and 3676 or equivalent. The influence of physical and chemical nonequilibrium, including surface effects, on gasdynamics, fluid mechanics and heat transfer. Flows including sound and shock waves, viscous waves and boundary layers, hypersonic shock layers and wakes, and channel and nozzle flows. Nonequilibrium processes including vibrational and chemical relaxation and, especially, radiative transfer of heat. Mr. Moore.

3682. SEMINAR IN HEAT TRANSFER (g)

Credit 3 hrs. Spring. 2-hr. meetings weekly to be arranged. Prerequisite, permission of professor in charge. Discussion of fields of active inquiry and current interest in heat transfer. Considerations of major recent work and several summaries of associated contributions. Mr. Gebhart.

3690. SPECIAL INVESTIGATIONS IN THERMAL ENGINEERING (u)

Credit by arrangement. Fall and spring. 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.

NUCLEAR SCIENCE AND ENGINEERING

(For description of courses see the section *Applied Physics*.)

STRUCTURAL ENGINEERING

(see page 123.)

THEORETICAL AND APPLIED MECHANICS

211. MECHANICS OF RIGID AND DEFORMABLE BODIES I (u)

Credit 4 hrs. Fall and spring. 2 Lect., 1 Rec., 1 Lab. Coregistration in Mathematics 293 and Physics 223. Force systems and equilibrium. Distributed forces, static friction, statically determinate plane structures. Concepts of stress and strain. Shearing force, bending moment, bending and torsion of beams. Analysis of plane stress and strain, combined stress, thermal stress. Theories of failure. Instability of columns. (Prelims: Oct. 17, Nov. 14, Dec. 12 at 7:30 P.M.) Staff.

212. MECHANICS OF RIGID AND DEFORMABLE BODIES II (u)

Credit 4 hrs. Spring. 2 Lect., 1 Rec., 1 Lab. Prerequisite, 211. Inelastic behavior. Energy methods in mechanics. Principles of particle dynamics. Theory of oscillations. Kinematics of rigid body motion. Dynamics of systems of particles. Kinetics of rigid bodies. (Prelims: Mar. 6, Mar. 27, May 8 at 7:30 P.M.) Staff.

1150. ADVANCED ENGINEERING ANALYSIS I (u)

Credit 3 hrs. Fall. Prerequisite, Mathematics 294 or equivalent. A course including 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. Use of the digital computer is included. Mr. Block.

1151. ADVANCED ENGINEERING ANALYSIS II (u)

Credit 3 hrs. Spring. Prerequisite, 1150 or equivalent. 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. Use of the digital computer is included. Mr. Block.

1157. BIONICS AND ROBOTS (u,g)

Credit 3 hrs. Fall. Prerequisites, elementary differential equations, linear algebra and probability, or consent of instructor. Engineering applications of strategies and tactics of biological systems. Machines that learn. Artificial intelligence. Cybernetics, information and adaptive control. Reliable systems from unreliable components. Self-organizing systems. Features in patterns. Neural nets, perceptrons, threshold logic, madelines. Brain models. Behavior models. Machines for proving theorems, playing games, navigating, exploring. Problems of sensors, perception, recognition and recall. Problems in machine learning of concepts, English, natural environments. Machine translation. Heuristic programming. Automata, pure and applied. Robots, hardware and software. Self-reproducing and self-repairing machines, models for embryology, development and evolution. Introduction to algebraic linguistics, Turing machines, and computability, Gödel's theorem, the Euler-Diderot metatheorem. Mr. Block.

1159. EXPERIMENTAL MECHANICS (u,g)

Credit 3 hrs. Fall. The student is expected to perform 4 to 6 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. Messrs. Robinson and Pao.

1160. CONTINUUM MECHANICS (u,g)

Credit 3 hrs. Fall. 3 Lect. A unified approach to the theory of continuous media based on thermodynamic and invariant principles. Kinematics of the continuum, stress hypothesis, uniqueness, constituitive equations. Special topics and examples from finite elasticity theory, the Navier-Stokes fluid and plasticity. Mr. Dafermos.

[1162. VIBRATION OF ELASTIC SYSTEMS (u,g)]

Credit 4 hrs. Spring. 3 Lect., 1 Lab. Review of vibration of linear lumped system 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. Not offered 1968–69.

1163. APPLIED ELASTICITY (u,g)

Credit 3 hrs. Fall. 3 Lect. 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. Mr. Conway.

[1164. THEORY OF ELASTICITY (g)]

Credit 3 hrs. Spring. 3 Lect. 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. Not offered 1968–69.

1165. MATHEMATICAL THEORY OF ELASTICITY (g)

Credit 3 hrs. Spring. 3 Lect. 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. Mr. Dafermos.

1166. STRESS WAVES IN SOLIDS (g)

Credit 3 hrs. Spring. 3 Lect. 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 wave-guides. Transient loads. Scattering of elastic waves and dynamical stress concentration. Waves in anisotropic media and visco-elastic media. Mr. Robinson.

1168. THEORY OF PLASTICITY (u,g)

Credit 3 hrs. Spring. 3 Lect. 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. Mr. Robinson.

1169. THERMAL STRESSES (g)

Credit 3 hrs. Fall. A treatment of the behavior of solids and structures at elevated temperatures. Thermomechanical coupling, inertia effects. Review of heat conduction in solids. Thermally induced vibrations. Elastic and inelastic stress analysis. Thermal buckling. Mr. Boley.

1170. ADVANCED DYNAMICS (u,g)

Credit 3 hrs. Fall. 3 Lect. Newton's equations for a system of particles, Lagrange's equations, Hamilton's principle, two-body problem, particle motion in non-Newtonian frames, rigid body motion. Euler's equations, tops, gyroscopes, variational principles of mechanics. Mr. Rand.

1172. SPACE FLIGHT MECHANICS (u,g)

Credit 3 hrs. Spring. 3 Lect. Gravitational potential of the earth; two-body problem; three-body problem; restricted three-body problem; Jacob'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. Mr. Alfriend.

1175. NONLINEAR VIBRATIONS (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 1162 or equivalent. Perturbation and iteration methods, phase-plane analysis, limit cycles, Lyapunov stability, Floquet theory, Mathieu's equation, graphical methods, method of Krylov-Bogoliubov, nonlinear vibrations of a continuous system. Mr. Rand.

1180. METHODS OF APPLIED MATHEMATICS I (g)

Credit 3 hrs. Fall. 3 Lect. Graduate students or undergraduate students with consent of instructor. Ordinary differential equations; series; orthogonal functions and Sturm-Liouville theory; Fourier transform; functions of several real variables; vector fields and integral theorems; matrices; partial differential equations. Development is based upon applications wherever possible. Mr. Greenberg.

1181. METHODS OF APPLIED MATHEMATICS II (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 1180 or the equivalent. Continuation of partial differential equations; Green's function; Fourier and Laplace transforms; complex variables; calculus of variations; tensor analysis. Development based largely upon applications; more so than in 1180. Mr. Greenberg.

1182. METHODS OF APPLIED MATHEMATICS III (g)

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 1181 or equivalent. 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. Development will be in terms of problems drawn from vibrations and acoustics, fluid mechanics and elasticity, heat transfer, electromagnetics. Mr. Thau.

1183. METHODS OF APPLIED MATHEMATICS IV (g)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 1182 or equivalent. More extensive treatment of 1182 in same spirit. Topics include: method of matched asymptotic expansions. W.K.B. 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. Mr. Thau.

1184. NUMERICAL METHODS IN ENGINEERING (g)

Credit 4 hrs. Spring. Prerequisite, 1181 or equivalent. Methods for obtaining numerical solutions to problems arising in engineering. Linear and non-linear 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. Mr. Block.

1196. RESEARCH IN THEORETICAL AND APPLIED MECHANICS (g)

Credit as arranged, any term. Thesis, literature survey or independent research on a subject of theoretical and applied mechanics. Such research must be under the guidance of a staff member. Staff.

1197. SELECTED TOPICS IN THEORETICAL AND APPLIED MECHANICS (g)

Credit as arranged, any term. Special lectures or seminars on subjects of current interest and in the Field of Theoretical and Applied Mechanics. Topics and credit hours to be announced when the course is offered. Staff.

THERMAL ENGINEERING

(see page 165.)

WATER RESOURCES ENGINEERING

(see page 126.)

UNIVERSITY ADMINISTRATION

James A. Perkins, President of the University.
Dale R. Corson, University Provost.
Mark Barlow, Jr., Vice President for Student Affairs.
Stuart M. Brown, Jr., Vice President for Academic Affairs.
John E. Burton, Vice President—Business.
Lewis H. Durland, University Treasurer.
W. Keith Kennedy, Vice Provost.
Franklin A. Long, Vice President for Research and Advanced Studies.
E. Hugh Luckey, Vice President for Medical Affairs.
Thomas W. Mackesey, Vice President for Planning.
Paul L. McKeegan, Director of the Budget.
Robert D. Miller, Dean of the University Faculty.
Steven Muller, Vice President for Public Affairs.
Arthur H. Peterson, University Controller.
Neal R. Stamp, Secretary of the Corporation, and University Counsel.

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Andrew Schultz, Jr., B.S., Ph.D., P.E., Dean of the College of Engineering; Professor of Industrial Engineering and Operations Research.
Edmund T. Cranch, B.M.E., Ph.D., Associate Dean of the College of Engineering; Professor of Theoretical and Applied Mechanics.
William H. Erickson, B.S., M.S., P.E., Associate Dean of the College of Engineering; Professor of Electrical Engineering.
John F. McManus, C.E., Assistant Dean of the College of Engineering.
Donald F. Berth, B.S.Ch.E., M.S.Ch.E., Assistant Dean of the College of Engineering; Lecturer in Engineering.
Donald G. Dickason, A.B., M.Ed., Director of Engineering Admissions and Student Personnel.
Donald B. Gordon, B.S.A.E., M.A., Coordinator, State Technical Services, and Director, Industrial Liaison for the College.
J. Eldred Hedrick, B.A., M.S., Ph.D., P.E., Director of Engineering Placement; Professor of Chemical Engineering.
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Julian C. Smith, B.Chem., Chem.E., P.E., Director of Continuing Education; Professor of Chemical Engineering.
Jeanette Wood, B.S., Librarian, College of Engineering Library.

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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.

Walter Wendall Cotner, B.S., E.E., M.E.E., Professor of Electrical Engineering, Emeritus.

Frederick Seward Erdman, B.S., B.S. in M.E., M.M.E., Ph.D., P.E., Professor of Mechanical Engineering, Emeritus.

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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.

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.

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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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P. G. Ashmore, M.A., Ph.D., Visiting Professor of Chemical Engineering.

Paul Baron, Dipl.Ing., Dr.Ing., Visiting Associate Professor of Civil Engineering.

Philip H. Calderbank, B.Sc., Ph.D., D.Sc., Visiting Professor of Chemical Engineering.

Brij Kishore Gupta, B.E.(Mech.), M.S., Ph.D., Visiting Assistant Professor of Machine Design.

Hilliard B. Huntington, B.A., M.A., Ph.D., Visiting Professor of Materials Science and Engineering.

Ivan Kuščer, B.A., Ph.D., Visiting Professor of Applied Physics and Aerospace Engineering.

Brian LeLievre, B.Eng., M.A.Sc., Ph.D., Visiting Assistant Professor of Civil Engineering.

Benjamin Joseph Leon, B.S., S.M., Sc.D., Visiting Professor of Electrical Engineering.

Marcel F. Neuts, License in Mathematics, M.S., Ph.D., Visiting Professor of Operations Research.

Amiram Ron, Ph.D., Visiting Professor of Applied Physics.

George Terzidis, B.S., M.S., Ph.D., Visiting Assistant Professor of Civil Engineering.

Stephen A. Thau, B.S.E., M.E.M., Ph.D., Visiting Associate Professor of Theoretical and Applied Mechanics.

FACULTY

Noble W. Abrahams, B.S. (Capt., U.S.N., Ret.), Assistant Professor of the Division of Basic Studies of the College of Engineering.

Kyle T. Alfriend, B.S., M.S., Ph.D., Assistant Professor of Theoretical and Applied Mechanics.

Robert N. Allen, B.S., Associate Professor of Industrial Engineering and Operations Research; Director of the Engineering Cooperative Program.

Paul D. Ankrum, B.S.E.E., A.B., M.S., Professor of Electrical Engineering.

Peter L. Auer, B.A., Ph.D, Professor of Aerospace Engineering; Director of the Laboratory for Plasma Studies.

Joseph M. Ballantyne, B.S., B.S.E.E., S.M., Ph.D., Associate Professor of Electrical Engineering.

Robert W. Balluffi, B.S., Ph.D., Professor of Materials Science and Engineering.

Boris W. Batterman, B.S., Ph.D., Professor of Materials Science and Engineering, and of Applied Physics.

Robert E. Bechhofer, A.B., Ph.D., Professor of Operations Research; Chairman of the Department.

Vaughn C. Behn, B.S., M.S., D.Eng., P.E., Associate Professor of Civil Engineering.

Donald J. Belcher, B.S., M.S., C.E., P.E., Professor of Civil Engineering.

Toby Berger, B.E., M.S., Ph.D., Assistant Professor of Electrical Engineering.

Richard H. Bernhard, B.M.E., M.S., Ph.D., Assistant Professor of Operations Research.

Donald F. Berth, B.S.Ch.E., M.S.Ch.E., Lecturer in Engineering; Assistant Dean of the College.

Louis J. Billera, B.S., M.A., Ph.D., Assistant Professor of Operations Research.

Richard D. Black, B.S.A.E., M.S.A.E., Ph.D., Associate Professor of Agricultural Engineering.

John M. Blakely, B.S., Ph.D., Associate Professor of Materials Science and Engineering.

George H. Blessis, B.E., M.E., P.E., Lecturer in Environmental Systems Engineering; Coordinator, Construction Industry Program—Continuing Education.

Henry D. Block, B.S., B.C.E., M.S., Ph.D., Professor of Applied Mathematics.

Bruno A. Boley, B.C.E., M.Ae.E., Sc.D., Robert P. Ripley Professor of Engineering; Professor of Theoretical and Applied Mechanics.

Ralph Bolgiano, Jr., B.S., B.E.E., M.E.E., Ph.D., Professor of Electrical Engineering.

John F. Booker, B.E., M.A.E., Ph.D., Associate Professor of Mechanical Engineering.

Neil M. Brice, B.Sc., M.Sc., Ph.D., Associate Professor of Electrical Engineering.

Kenneth M. Brown, B.S., M.S., Ph.D., Assistant Professor of Computer Science.

Mark Brown, B.S., M.S., Ph.D., Assistant Professor of Operations Research.

Wilfried Brutsaert, A.E., M.S., Ph.D., Associate Professor of Civil Engineering.

Nelson H. Bryant, E.E., M.E.E., Associate Professor of Electrical Engineering.

Arthur H. Burr, B.S., M.S., Ph.D., Hiram Sibley Professor of Mechanical Engineering (on leave, academic year 1968–69).

Malcolm S. Burton, B.S., S.M., Professor of Materials Science and Engineering; Assistant Director of the Department.

K. Bingham Cady, B.S., Ph.D., Associate Professor of Applied Physics; Representative of the Engineering Field of Nuclear Engineering.

Herbert J. Carlin, B.S., M.S., D.E.E., J. Preston Levis Professor of Engineering; Professor of Electrical Engineering; Director of the School.

David D. Clark, A.B., Ph.D., Professor of Applied Physics; Director of the Nuclear Reactor Laboratory (on leave, academic year 1968–69).

Roderick K. Clayton, B.S., Ph.D., Professor of Applied Physics, and of Biology and Biophysics.

George G. Cocks, B.S., Ph.D., Associate Professor of Chemical Engineering.

Robert L. Constable, B.A., M.A., Ph.D., Assistant Professor of Computer Science.

Bartholomew J. Conta, B.S., M.S., Professor of Mechanical Engineering.

Harry D. Conway, B.Sc., M.A., Ph.D., D.Sc., Professor of Theoretical and Applied Mechanics.

Richard W. Conway, B.M.E., Ph.D., Professor of Operations Research, and of Computer Science; Director of the Office of Computer Services (on leave, academic year 1968–69).

J. Robert Cooke, B.S., M.S., Ph.D., Assistant Professor of Agricultural Engineering.

Terrill A. Cool, B.S., M.S., Ph.D., Assistant Professor of Thermal Engineering.

Dale R. Corson, A.B., A.M., Ph.D., Professor of Applied Physics, and of Physics; Provost of the University.

Edmund T. Cranch, B.M.E., Ph.D., Professor of Theoretical and Applied Mechanics; Chairman of the Department; Professor of Engineering Physics, and of Mechanical Engineering; Associate Dean of the College of Engineering.

Renwick E. Curry, B.A., B.S., M.S., Sc.D., Assistant Professor of Electrical Engineering.

Trevor R. Cuykendall, B.S., M.S., Ph.D., Spencer T. Olin Professor of Engineering; Professor of Engineering Physics, and of Applied Physics; Director of the School of Engineering Physics.

Constantine M. Dafermos, Dipl.C.E., Ph.D., Assistant Professor of Theoretical and Applied Mechanics.

Stella C. Dafermos, Dipl.C.E., Ph.D., Instructor of Operations Research.

G. Conrad Dalman, B.E.E., M.E.E., D.E.E., Professor of Electrical Engineering.

P. C. Tobias de Boer, Ir., M.E., Ph.D., Associate Professor of Aerospace Engineering.

David Dropkin, M.E., M.M.E., Ph.D., Professor of Mechanical Engineering; Representative of the Graduate Field.

George B. DuBois, A.B., M.E., P.E., Professor of Mechanical Engineering.

Leonard B. Dworsky, B.S.C.E., M.A., Professor of Civil Engineering; Director of the Water Resources Center.

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Victor H. Edwards, B.A., Ph.D., Assistant Professor of Chemical Engineering.

Hamilton Emmons, A.B., M.S., Ph.D., Assistant Professor of Operations Research.

William H. Erickson, B.S., M.S., P.E., Professor of Electrical Engineering; Associate Dean of the College of Engineering.

Samuel J. Errera, B.S., M.S., Ph.D., Associate Professor of Civil Engineering (on leave, academic year 1968–69).

Melvin I. Esrig, B.B.A., B.C.E., M.S., Ph.D., P.E., Associate Professor of Civil Engineering (on leave, academic year 1968–69).

Howard N. Fairchild, M.E., E.E., P.E., Professor of Mechanical Engineering.

Louis M. Falkson, A.B., A.M., Ph.D., Assistant Professor of Environmental Systems Engineering.

Donald T. Farley, B.E.P., Ph.D., Professor of Electrical Engineering.

Terrence L. Fine, B.E.E., S.M., Ph.D., Assistant Professor of Electrical Engineering.

Robert K. Finn, Ch.E., Ph.D., Professor of Chemical Engineering, and of Nutrition.

Gordon P. Fisher, B.E., D.Eng., P.E., Professor of Civil Engineering; Chairman of the Department of Environmental Systems Engineering.

Hans H. Fleischmann, Dipl.Phys., Dr.rer.nat., Associate Professor of Applied Physics.

Orval C. French, B.S.A.E., M.S.A.E., Professor of Agricultural Engineering; Head of the Department; Chairman of the Joint Faculty Committee on Agricultural Engineering.

Ronald B. Furry, B.S., M.S., Ph.D., Associate Professor of Agricultural Engineering.

Richard H. Gallagher, B.C.E., M.C.E., Ph.D., P.E., Professor of Civil Engineering.

Charles D. Gates, B.A., M.S., Professor of Civil Engineering; Chairman of the Department of Water Resources Engineering; Representative of the Graduate Field of Water Resources.

Benjamin Gebhart, B.S.E., M.S.E., Ph.D., Professor of Mechanical Engineering.

Roger L. Geer, M.E., Professor of Mechanical Engineering.

Albert R. George, B.S.E., M.A., Ph.D., Assistant Professor of Aerospace Engineering.

Peter Gergely, B.Eng., M.S., Ph.D., P.E., Associate Professor of Civil Engineering.

Thomas Gold, B.A., M.A., Professor of Electrical Engineering, and of Astronomy.

Henry P. Goode, B.S., M.S., P.E., Professor of Industrial Engineering and Operations Research.

Michael D. Greenberg, B.M.E., M.S., Ph.D., Assistant Professor of Theoretical and Applied Mechanics.

Wesley W. Gunkel, B.S.A.E., M.S.A.E., Ph.D., Professor of Agricultural Engineering; Representative of the Graduate Field.

Peter Harriott, B.Chem.E., Sc.D., Professor of Chemical Engineering.

Paul L. Hartman, B.S.E.E., Ph.D., Professor of Applied Physics, and of Physics.

Juris Hartmanis, Cand.Phil., M.A., Ph.D., Professor of Computer Science; Chairman of the Department.

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William L. Hewitt, A.B., B.C.E., M.C.E., P.E., Associate Professor of Civil Engineering; Acting Director of the School.

Paul S. Ho, B.S., M.S., Ph.D., Assistant Professor of Materials Science and Engineering.

Bernd Hoefflinger, Dipl.Phys., Dr.rer.nat., Assistant Professor of Electrical Engineering.

John E. Hopcroft, B.S., M.S., Ph.D., Associate Professor of Computer Science; Representative of the Graduate Field.

Clyde E. Ingalls, E.E., P.E., Professor of Electrical Engineering.

Joseph O. Jeffrey, M.E., M.M.E., Professor of Materials Science and Engineering.

Frederick Jelinek, S.B., S.M., Ph.D., Associate Professor of Electrical Engineering (on leave, academic year 1968–69).

Herbert H. Johnson, B.S., M.S., Ph.D., Professor of Materials Science and Engineering.

Myunghwan Kim, B.S., M.E., Ph.D., Associate Professor of Electrical Engineering (on leave, academic year 1968–69).

Kenneth O. Kortanek, B.S., B.A., M.A., Ph.D., Associate Professor of Operations Research.

Edward J. Kramer, B.Ch.E., Ph.D., Assistant Professor of Materials Science and Engineering.
Allan I. Krauter, M.E., M.S., Ph.D., Assistant Professor of Mechanical Engineering.
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Charles A. Lee, B.E.E., Ph.D., Associate Professor of Electrical Engineering.
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Taylor D. Lewis, B.S.E., C.E., P.E., Professor of Civil Engineering.
Che-Yu Li, B.S.E., Ph.D., Associate Professor of Materials Science and Engineering; Representative of the Graduate Field.
Ta Liang, B.E., M.C.E., Ph.D., Professor of Civil Engineering.
Richard L. Liboff, A.B., Ph.D., Associate Professor of Electrical Engineering.
James A. Liggett, B.S.C.E., M.S., Ph.D., Associate Professor of Civil Engineering.
Simpson Linke, B.S., M.E.E., Professor of Electrical Engineering.
Raymond C. Loehr, B.S., M.S., Ph.D., Professor of Agricultural Engineering, and of Civil Engineering.
Howard A. Longhouse, B.S.A.E., M.S.A.E., Lecturer in Agricultural Engineering.
Robert T. Lorenzen, B.S., B.S.C.E., M.S., Associate Professor of Agricultural Engineering.
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David C. Ludington, B.S., M.S., Ph.D., Associate Professor of Agricultural Engineering.
Walter R. Lynn, B.S.C.E., M.S.C.E., Ph.D., Professor of Civil Engineering; Director of the Center for Environmental Quality Management (on leave, academic year 1968–69).
George B. Lyon, B.S., M.S., P.E., Associate Professor of Civil Engineering.
Lee A. MacKenzie, B.E.E., M.S., Ph.D., Associate Professor of Electrical Engineering (on leave, fall term 1968).
William L. Maxwell, B.M.E., Ph.D., Associate Professor of Operations Research (on leave, academic year 1968–69).
Henry S. McGaughan, B.S.E.(in Physics), M.E.E., Professor of Electrical Engineering.
William McGuire, B.S.C.E., M.C.E., P.E., Professor of Civil Engineering (on leave, academic year 1968–69).
Paul R. McIsaac, B.E.E., M.S.E., Ph.D., Professor of Electrical Engineering.
Howard N. McManus, Jr., B.S.M.E., M.S., Ph.D., Professor of Mechanical Engineering; Chairman of the Department of Machine Design and Materials Processing.
Arthur J. McNair, B.S., M.S., C.E., P.E., Professor of Civil Engineering.
Ross McPherson, B.S., M.S., Ph.D., Assistant Professor of Applied Physics; Representative of the Graduate Field of Nuclear Science and Engineering.
Charles W. Merriam III, Sc.B., M.S., Sc.D., Professor of Electrical Engineering.
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Howard L. Morgan, B.S., Ph.D., Assistant Professor of Operations Research and Computer Science.

John R. Moynihan, M.E., M.M.E., P.E., Professor of Theoretical and Applied Mechanics; Assistant Chairman of the Department.

John A. Nation, B.Sc., A.R.C.S., Ph.D., D.I.C., Assistant Professor of Electrical Engineering.

Mark S. Nelkin, S.B., Ph.D., Professor of Applied Physics (on leave, academic year 1968–69).

Herbert F. Newhall, A.B., Ph.D., Professor of Applied Physics, and of Physics.

Benjamin Nichols, B.E.E., M.E.E., Ph.D., Professor of Electrical Engineering; Representative of the Graduate Field.

Arthur H. Nilson, B.S.C.E., M.S., Ph.D., P.E., Associate Professor of Civil Engineering; Representative of the Graduate Field.

Sidney Oldberg, M.E., Professor of Machine Design and Materials Processing.

Robert E. Osborn, B.S.E.E., P.E., Associate Professor of Electrical Engineering.

Edward Ott, B.S.E.E., M.S., Ph.D., Assistant Professor of Electrical Engineering.

Walter S. Owen, B.Eng., M.Eng., Ph.D., Thomas R. Briggs Professor of Engineering; Professor of Materials Science and Engineering; Director of the Department.

Yih-Hsing Pao, B.S., M.S., Ph.D., Professor of Theoretical and Applied Mechanics; Representative of the Graduate Field.

Richard M. Phelan, B.S., M.M.E., Professor of Mechanical Engineering.

Christopher Pottle, B.E., M.S., Ph.D., Associate Professor of Electrical Engineering.

Narahari U. Prabhu, B.A., M.A., M.Sc., Professor of Operations Research.

Richard H. Rand, B.E., M.S.Eng., Sc.D., Assistant Professor of Theoretical and Applied Mechanics.

Gerald E. Rehkugler, B.S., M.S., Ph.D., Associate Professor of Agricultural Engineering.

Edwin L. Resler, Jr., B.S.Aero.E., Ph.D., Joseph Newton Pew, Jr. Professor in Engineering; Professor of Aerospace Engineering, of Electrical Engineering, and of Applied Physics; Director of the Graduate School of Aerospace Engineering.

Charles S. ReVelle, B.Ch.E., Ph.D., Assistant Professor of Civil Engineering (on leave, academic year 1968–69).

Thor N. Rhodin, B.S., A.M., Ph.D., Professor of Applied Physics.

David N. Robinson, B.S., M.S., Ph.D., Assistant Professor of Theoretical and Applied Mechanics.

Ferdinand Rodriguez, B.S., M.S., Ph.D., Associate Professor of Chemical Engineering.

Joseph L. Rosson, B.S., M.E.E., Associate Professor of Electrical Engineering; Assistant Director of the School.

Norman Rostoker, B.A.Sc., M.A., Sc.D., IBM Professor of Engineering; Professor of Applied Physics; Chairman of the Department.

Michael Rubinovitch, B.Sc., Ph.D., Assistant Professor of Operations Research.

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Mrs. Miriam M. Salpeter, B.A., M.A., Ph.D., Associate Professor of Applied Physics.

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Stephen L. Sass, B.Ch.E., Ph.D., Assistant Professor of Materials Science and Engineering.

Byron W. Saunders, B.S., M.S., Professor of Industrial Engineering and Operations Research; Director of the School.

Eraldus Scala, B.S., M.S., D.Eng., Professor of Materials Science and Engineering.

George F. Scheele, B.S.E., M.S., Ph.D., Assistant Professor of Chemical Engineering.

Andrew Schultz, Jr., B.S., Ph.D., P.E., Professor of Industrial Engineering and Operations Research; Dean of the College of Engineering.

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William R. Sears, B.Aero.E., Ph.D., John LaPorte Given Professor of Engineering; Professor of Aerospace Engineering.

A. Richard Seebass III, B.S.E., M.S.E., Ph.D., Associate Professor of Aerospace Engineering.

David N. Seidman, B.S., M.S., Ph.D., Assistant Professor of Materials Science and Engineering.

Robert G. Sexsmith, B.A.Sc., M.S., Ph.D., Assistant Professor of Civil Engineering.

Alan C. Shaw, B.A., Ph.D., Assistant Professor of Computer Science.

Shan Fu Shen, B.S., Sc.D., Professor of Aerospace Engineering.

Edwin S. Shepardson, B.S., M.S., Professor of Agricultural Engineering.

Dennis G. Shepherd, B.S., Professor of Mechanical Engineering; Director of the Sibley School of Mechanical Engineering (on leave, spring term 1969).

Benjamin M. Siegel, B.S., Ph.D., Professor of Applied Physics, and of Physics.

John Silcox, B.S., Ph.D., Associate Professor of Applied Physics.

Floyd O. Slate, B.S., M.S., Ph.D., Associate Professor of Civil Engineering.

Neil J. A. Sloane, B.E.E., B.A., M.S., Ph.D., Assistant Professor of Electrical Engineering.

George V. Smith, B.S., Sc.D., P.E., Francis Norwood Bard Professor of Metallurgical Engineering; Professor of Materials Science and Engineering.

Howard G. Smith, E.E., M.E.E., Ph.D., Professor of Electrical Engineering; Director of the Division of Basic Studies of the College of Engineering.

Julian C. Smith, B.Chem., Chem.E., P.E., Professor of Chemical Engineering; Director of Continuing Education.

James W. Spencer, B.C.E., M.C.E., Ph.D., P.E., Professor of Agricultural Engineering.

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