Cornell University

ANNOUNCEMENTS

College of Engineering

Courses and Curricula

1966-67

FURTHER INFORMATION

UNDERGRADUATES

All prospective engineering students should write for a copy of the *Announcement of General Information,* which describes the University community in greater detail. *Engineering at Cornell,* an illustrated Announcement prepared especially for pre-college 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* 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
Courses and Curricula

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Academic Calendar

	1966–67
Freshman Orientation	S, Sept. 17
Registration, new students	M, Sept. 19
Registration, old students	T, Sept. 20
Instruction begins, 1 p.m.	W, Sept. 21
Midterm grades due	W, Nov. 9
Thanksgiving recess:	
Instruction suspended, 12:50 p.m.	W, Nov. 23
Instruction resumed, 8 a.m.	M, Nov. 28
Christmas recess:	
Instruction suspended, 10 p.m.	W, Dec. 21
Instruction resumed, 8 a.m.	Th, Jan. 5
First-term instruction ends	S, Jan. 21
Registration, old students	M, Jan. 23
Examinations begin	T, Jan. 24
Examinations end	W, Feb. 1
Midyear recess	Th, Feb. 2
Midyear recess	F, Feb. 3
Registration, new students	S, Feb. 4
Second-term instruction begins, 8 a.m.	M, Feb. 6
Midterm grades due	S, Mar. 25
Spring recess:	
Instruction suspended, 12:50 p.m.	S, Mar. 25
Instruction resumed, 8 a.m.	M, Apr. 3
Second-term instruction ends, 12:50 p.m.	S, May 27
Final examinations begin	M, May 29
Final examinations end	T, June 6
Commencement Day	M, June 12

ACADEMIC CALENDAR FOR 1967–68. Orientation for new students (dates to be determined). Registration: new students, F, Sept. 8; old students, S, Sept. 9. First-term instruction begins, 7:30 a.m., M, Sept. 11. Midterm grades due, S, Oct. 21. Thanksgiving recess: instruction suspended, 1:10 p.m. W, Nov. 22; resumed, 7:30 a.m., M, Nov. 27. First-term instruction ends, 1:10 p.m., S. Dec. 16. Christmas recess. Independent study period begins, W, Jan. 3. Examinations begin, M, Jan. 8; end, T, Jan. 16. Intersession begins, W, Jan. 17. Registration: new students, F, Jan. 26; old students, S, Jan. 27. Second-term instruction begins, 7:30 a.m., M, Jan. 29. Midterm grades due, S, Mar. 9. Spring recess: instruction suspended, 1:10 p.m., S, Mar. 23; resumed, 7:30 a.m., M, Apr. 1. Second-term instruction ends, 1:10 p.m., S, May 11. Independent study period begins, M, May 13. Examinations begin, M, May 20; end, T, May 28. Commencement Day, M, June 3.

CORNELL UNIVERSITY ANNOUNCEMENTS
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Contents

Cornell University

ENGINEERING AT CORNELL

In engineering today, one factor is constant: change. Change is so swift that today's engineering student must be offered a dynamically flexible curriculum which will match his education with the engineering profession's continually changing needs. In its long and distinguished history, the College of Engineering at Cornell has consistently been a leader in the pioneering of engineering programs to meet such needs.

When the University was founded more than one hundred years ago, engineering became an integral part of the range of studies undertaken. At that time Cornell was considered a radical experiment — radical in its assumption that such studies as engineering and agriculture could be developed along with liberal arts programs, and that all could profit from such a close association. The founder and first major benefactor, Ezra Cornell, saw the need for an educational institution that would blend the best of traditional, classical studies with programs that could greatly aid in the total development of the pioneering nation. Cornell, himself, did considerable pioneering work in aiding Samuel F. B. Morse by laying the first telegraph line between Baltimore and Washington, and later he became a major stockholder in the Western Union Telegraph Company.

Cornell's motto, "I would found an institution where any person can find instruction in any study," represented the beginnings of what we know today as the true university concept in higher education. In addition to the College of Engineering, Cornell has six other divisions to which secondary-school students may be admitted — Agriculture, Architecture, Arts and Sciences, Home Economics, Hotel Administration, Industrial and Labor Relations — as well as graduate divisions, such as those in law, veterinary medicine, business and public administration, nutrition, nursing, and medicine. All but the latter two are in Ithaca, New York, on a campus that is generally regarded as one of the most beautiful in America. The School of Nursing and the Medical College are in New York City.

Engineering students, both graduate and undergraduate, not only are a part of a distinguished engineering college but are also part of the whole of Cornell where they may draw upon the strengths of the whole University for educational development. In Cornell, as in society at large, there are no requirements which force students through the same educational mold. There is a smooth and continuous gradation of educational patterns among Cornell students, and the patterns are sufficiently diverse to match their individual interests and at the same time to provide society with graduates whose composite capabilities are as broad and continuous as the requirements of the engineering profession itself.

Among some of the engineering firsts, Cornell developed the first undergraduate electrical engineering program in the nation, was one of the pioneers in the early development of industrial, mechanical, and engineering physics curricula. In addition, Cornell was the first to award graduate degrees in engineering – the degree of Civil Engineer in 1870 and in 1872, the doctorate in civil engineering. Those degrees were also the first Cornell awarded in any graduate study. In 1885, the first doctorate in electrical engineering was granted. One of the major national scientific fraternities, Sigma Xi, was founded at Cornell in 1886 by Professor Henry Williams of Mechanical Engineering.

Today approximately 2,000 undergraduate engineers are enrolled in the various schools and departments of the College. In addition, about 700 full-time students are working on advanced degrees with aims covering every portion of the broad spectrum of the engineering profession. Two hundred engineering faculty members, complemented by faculties in the University's science and mathematics departments, give strong support to these students as they explore established and new areas of technology, within the atmosphere of a great university.

The accelerating expansion of modern science and technology poses a complex and exciting challenge for engineering education to keep pace with the present, and in fact to lead for the future. Every division of the College is committed to improving its undergraduate programs and to advancing graduate education and research, in order to provide Cornell engineers 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 degree levels: Bachelor of Science, Master of Engineering, Master of Science, and Doctor of Philosophy.

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 freshman and sophomore engineering students are enrolled in the Division of Basic Studies (see page 31) 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*

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 26).
Chemical Engineering (see page 35).
Civil Engineering (see page 41).
Electrical Engineering (see page 46).
Engineering Physics (see page 52).
Industrial Engineering and Operations Research (see page 58).
Materials Science and Engineering (see page 65).
Mechanical Engineering (see page 71).
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 12).

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 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 23).
Agricultural Engineering (see page 26).
Chemical Engineering (see page 35).
Civil Engineering (see page 41).
Electrical Engineering (see page 46).
Engineering Physics (see page 52).
Industrial Engineering and Operations Research (see page 58).
Materials Science and Engineering (see page 65).
Mechanical Engineering (see page 71).
Nuclear Engineering (see page 77).

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

MASTER OF SCIENCE AND DOCTOR OF PHILOSOPHY DEGREES

For these 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 MATHEMATICS (with Arts and Sciences)

Applied Mathematics.

APPLIED PHYSICS (with Arts and Sciences)

Applied Physics.

ASTRONOMY AND SPACE SCIENCES (with Arts and Sciences)

Astronomy, Astrophysics, Magnetohydrodynamics, Radiophysics, Space Sciences (General).

CHEMICAL ENGINEERING

Biochemical Engineering, Chemical Engineering, General. Chemical Processes and Process Control, Materials Engineering, Nuclear Process Engineering.

CIVIL ENGINEERING

Aerial Photographic Studies, Construction Engineering and Administration, Geodetic and Photogrammetric Engineering, Hydraulics, Hydraulic Engineering, Sanitary Engineering, Sanitary Sciences, Soils Engineering, Structural Engineering, Structural Mechanics, Transportation Engineering.

ELECTRICAL ENGINEERING

Communication Engineering, Control Systems Engineering, Electrical Engineering, General. Illuminating Engineering, Power Engineering.

INDUSTRIAL ENGINEERING AND 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
Engineering Drawing, Machine Design, Materials Processing, Thermal Environment, 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

Ten modern, spacious buildings bring teaching and research together in 14 acres of floor space, and house the finest of equipment. Several of these buildings have been gifts from distinguished Cornell alumni.

Complementing these new engineering facilities is a new physical sciences building, Clark Hall. Along with the modernization and additional construction under way in physics and chemistry, nearly 20 million dollars will have been spent by the University on strengthening its resources in the physical sciences by 1967. In addition, the construction of a new life sciences building is already under way.

Descriptions of facilities for the instructional areas in the College are in the section "Areas of Instruction."

Library Resources

The engineering library, in Carpenter Hall, houses a collection of some 90,000 books and periodicals. The library's pleasant atmosphere is created by the attractive design of the building, the convenient arrangement of its facilities, and its handsome furnishings. In addition to the conventional facilities for reading and research, comfortable chairs for leisurely reading, individual study tables, and a typing and microtext reading room are provided. A staff of professional librarians furnishes reference, bibliographical, reserve, and circulation services.

Among the specialized holdings of the Engineering Library are included a full depository collection of the U.S. Atomic Energy Commission and similar reports from about 20 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 2,600,000 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.

Historical literature in all the sciences is in the collections of the Olin Graduate and Research Library, which provides study accommodations for 1,000 readers and shelves for two million volumes. A variety of bibliographical, physical and service facilities are provided. Equipment is designed to facilitate use of library materials by students, faculty, and researchers. In the card catalog and bibliography area are the union card catalog and union serials catalog of all books and journals on the Ithaca campus. Also there are the published catalogs of the great libraries of the world, together with the principal indexes, abstracts, and other guides to the literature in the various subject fields. This centralized facility is designed to help researchers keep abreast of new developments in their fields without going from one special collection to another.

A room for the use of microtext material accommodates 24 readers, each with its own microfilm machine and adequate space for note taking. Adjacent is a room in which microfilm and other types of copies of library materials can be made at nominal cost. This eliminates the need for copious note-taking and allows greater use of material that is in great demand.

Another special facility is the map room. The Library has a current collection of about 50,000 maps, storage space for tripling the collection, specially-designed work and consultation facilities, and light-tables for tracing copies of maps.

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 seek employment.

Students intending to engage in the practice of professional engineering will be encouraged to continue their studies for one additional year beyond the Bachelor's degree, and will receive a professional Master's degree. This is an integrated undergraduate-graduate program which accounts for the somewhat shorter period of time required to earn both degrees.

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.

THE 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.* (Both Field Programs and the *College Program* are described in the sections which follow.)

All freshmen undertake a common program of studies, except for those obtaining 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 year. 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 CORC, the Cornell computing language, while enrolled in this latter course, and make subsequent use of it in their mathematics, science, and engineering courses. Both of these introductory courses encourage close student-faculty association. Advisers drawn from the College's faculty provide another opportunity for students to become more acquainted with the many opportunities open to them in the Cornell programs.

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 sciences, twelve credit hours of liberal electives and six credit hours of unspecified electives during his junior and senior years.

FIELD PROGRAMS

Students intending to enter practice in one of the several traditional engineering fields taught by the College will enroll in a Field Program in their junior year. At present, Field Programs are offered in agricultural, chemical, civil, electrical, and mechanical engineering, industrial engineering and operations research, plus engineering physics, and materials science and engineering. To prepare for entry to one of these fields, the appropriate engineering science courses would be selected during the sophomore year (see the Common Studies Core, page 11). For example, a student considering electrical engineering might take courses in electrical science and mechanics as his preparatory engineering science courses during the sophomore year.

In any of these several fields, further core studies are continued through required liberal electives, free electives, and additional engineering science electives. Approximately 30 percent of the four-year program is devoted to professional studies of a chosen field.

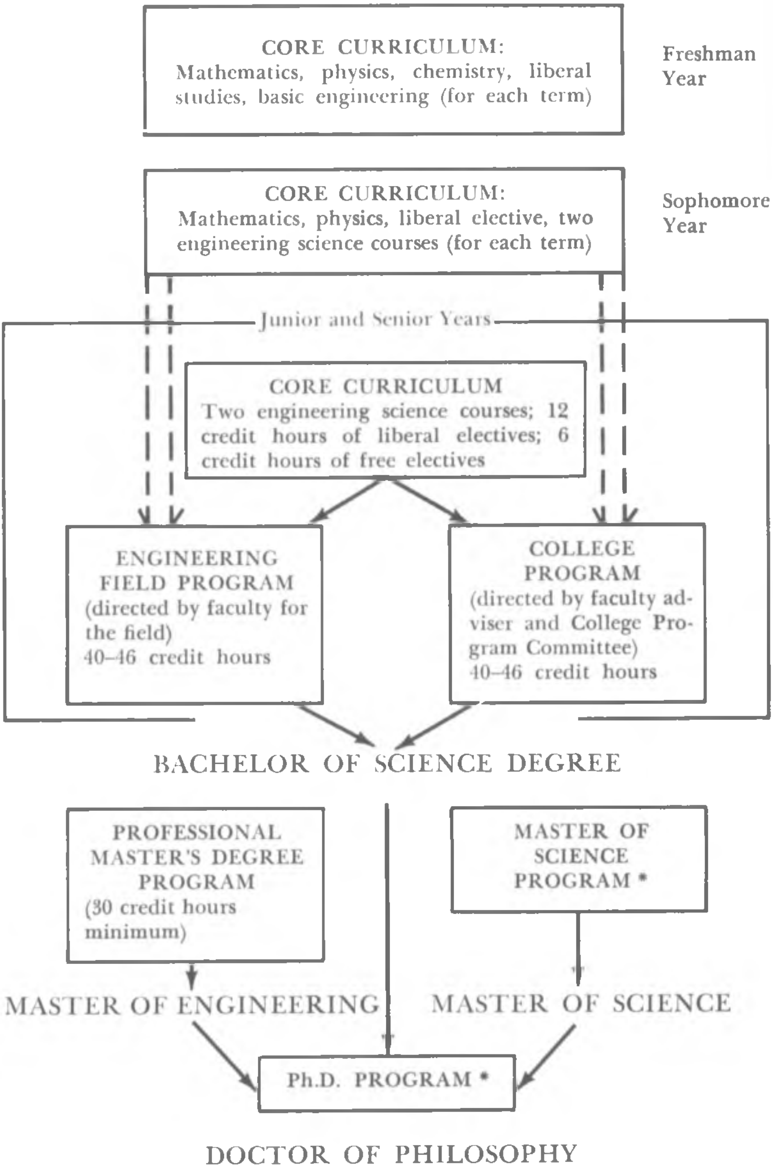
At the completion of the four-year Field Program, a graduate may be admitted to the College's professional Master's degree program, earning that degree in one additional year. The professional Master's degree program represents the level at which graduates will be prepared to seek *professional* engineering 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 in modern industry.

Individuals seeking careers in research in applied science or in a specialized engineering area, such as sanitary engineering within civil engineering, can apply for the Master of Science or the Ph.D. 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 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 stage.

THE COLLEGE PROGRAM

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 non-engineering discipline. Many combinations are possible under the program as established and the College Program Committee, which administers the program, approves all pro-

SUMMARY OF DEGREE REQUIREMENTS FOR B.S., M.ENG., M.S., AND Ph.D.



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

posals 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 the Field Programs in that the courses to satisfy the 40 to 46 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 normally is made at the beginning of the student's junior year but applications to the program are accepted as early as the second term of the freshman year.

Within these 40 to 46 credit hours, the student is required to have at least a minimum of 12 hours in an engineering major, 8 hours in an engineering minor, and 8 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 non-engineering 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.

THE INDUSTRIAL COOPERATIVE PROGRAM

During the fourth term, an above-average student who intends to pursue a program in electrical, industrial, or mechanical engineering, or engineering physics, may apply for admission to the Industrial Cooperative Program.

If accepted in that program he will have an opportunity to gain practical experience in his chosen field, which can be of value to him in planning his program and carrying out his studies. In addition, he not only earns a substantial salary during his periods of employment, but also gains about a year in the amount of responsibility he can undertake upon graduation.

By utilizing the summers following his second, third, and fourth years, the student is able to complete the academic requirements for his Bachelor's and Master's degrees, pursue his work program totaling nearly one year in industry, and still graduate with his class on time. He is on campus with his regular classmates except during the fifth term.

The schedule for the Cooperative Program, beginning after the fourth term, is as follows:

Summer:	Fifth term courses
Fall:	Industry
Spring:	Sixth term courses
Summer:	Industry
Fall:	Seventh term courses
Spring:	Eighth term courses
(Award of B.S. Degree)	
Summer:	Industry

Students who seek a Master's degree are able to begin graduate study in the fall following receipt of the Bachelor's degree, just as in the regular program.

The work program of each participant is arranged to advance his individual interests and aptitudes within the regular activity of the company with which he is affiliated. Because the plan visualizes progression from less demanding assignments through to development, research, and other more advanced responsibilities, it is not feasible for any one student to work in more than one company. He is therefore admitted to the program by arrangement with one company and is in their employ throughout the program. Neither the student nor the company, however, is obligated in any sense for employment beyond the completion of the Industrial Cooperative Program.

Among the companies presently participating in the Program are American Electric Power Service Corporation, Anaconda Wire and Cable Company, Campbell Soup Company, Cornell Aeronautical Laboratory, The Emerson Electric Manufacturing Company, General Electric Company, General Radio Company, Gleason Works, Hewlett-Packard Company, Humble Oil and Refining Company, International Business Machines Corporation, Pall Trinity Micro Corporation, and Raytheon Manufacturing Company.

Further information is available from the Industrial Cooperative Program office, 109 Phillips 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*
English	4
History	2
One foreign language	2
Algebra (elementary and intermediate)	2
Plane geometry	1
Trigonometry	1/2
Advanced algebra or solid geometry	1/2
Chemistry	1
Physics	1

College Board Tests

The Scholastic Aptitude Test of the College Entrance Examination Board is required of all applicants. All applicants also must take the College Board achievement tests in mathematics and in chemistry or physics. The Level I achievement test in mathematics is required of all applicants and must be taken not later than January of the senior year. Applicants should take the achievement test in chemistry or physics in May of the junior year, or in December or January of the senior year, provided they have completed one year of study in the subject in the junior year.

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 in 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.

Transfer and Special Students

Students desiring to transfer to the College of Engineering from another Cornell division or from another university or college are invited to communicate with the Director of the Division of Basic Studies, Hollister Hall, if they have the equivalent of two or fewer years of applicable college credit. If it appears that the equivalent of all the courses of the Basic Studies curriculum (pages 32–34) has been successfully completed, prospective students should communicate with the Director of the professional school in which they are interested.

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 (M.S. or Ph.D.) or for the professional engineering degrees — Master of Engineering (Aerospace, Agricultural, Chemical, Civil, Electrical, Engineering Physics, Industrial, Mechanical, Materials, or Nuclear).

General Degrees

The M.S. and Ph.D. 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* 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, electrical, industrial engineering and operations research, materials science and engineering, mechanical, and nuclear engineering, and in applied 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 30 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.

The professional degrees are at the fifth-year level of university work and require, in general, one year of additional study beyond a four-year baccalaureate program. Cornell alumni who received the five-year Bachelor of Engineering degree not more than six years prior to the date of their entering the graduate program, may — if they have made a sufficiently strong academic record in specified technical courses — be able to complete the requirements for the Master of Engineering degree in one term of fifteen credit hours. Candidates may be admitted to some of the professional programs with minor deficiencies to be made up during their graduate study; in such cases more than two terms of work may be required.

A candidate interested in entering the graduate professional program should write to the director of the division of engineering he plans to enter.

TUITION AND FINANCIAL AID

TUITION AND FEES

Tuition in the College of Engineering is $775 per term. In addition, there is a University General Fee of $200 per term. The latter contributes toward the various services provided by the University, such as the libraries, the clinic and hospital, recreational facilities, and the student center in Willard Straight Hall.

For further information relating to payment of tuition and fees, refunds, application and registration fees, estimates of living expenses, etc., 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. Nearly a quarter of a million dollars is awarded annually by the University to engineering freshmen alone. Recently over 65 per cent of all undergraduate engineering students have held scholarships or grants-in-aid, exclusive of loans.

Freshmen seeking financial assistance file a single application with the University Office of Scholarships and Financial Aid. Those who receive scholarships administered by the College of Engineering should deal directly with the Office of Student Personnel of the College of Engineering on any question relating to these awards. Specifically, these are the scholarships awarded to incoming freshmen which they may continue to hold throughout their college course.

Upperclassmen with financial need, who did not receive Cornell awards at the time of entrance, should initiate all applications for financial aid with the Office of Scholarships and Financial Aid, Day Hall. A booklet listing all scholarships and loans available to students is published by that office. Upperclassmen who thus apply for financial assistance will be interviewed by scholarship committees before awards are made, but their applications must originate with the Office of Scholarships and Financial Aid.

GRADUATE FINANCIAL AID

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

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

STUDENT LIFE AT CORNELL

HOUSING

University residence halls, located within convenient distance of 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 the opportunity of participating 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 22 sports. In addition, the various athletic facilities are available for intramural and informal competition.

Throughout the year, there are several 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 and at the Art Room of Willard Straight Hall.

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 almost anyone's hobby.

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 throughout 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 students concentrate 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-Study 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 point of reference 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 consult 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 nonacademic 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

AEROSPACE ENGINEERING (GRADUATE PROGRAM)

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 is the field of engineering that 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 this School 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, 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 upon 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 holding baccalaureate degrees (or equivalent) in any branch of engineering, mathematics, or the physical sciences from qualified institutions, provided that their undergraduate scholastic records are such as to indicate ability to handle 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, Cornell University. 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 M.Eng. (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 four areas of aerospace engineering: (1) fluid mechanics; (2) high temperature gasdynamics; (3) magnetohydrodynamics; and (4) space mechanics. 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, aerospace structures, aerophysics, chemical kinetics, etc. Faculty members and visiting staff frequently offer additional courses (besides those listed on page 23) in their specialty.

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 30 credit hours. Exceptions in rare instances may be made at the discretion of the faculty.

Course Sequences Available for M.Eng. (Aerospace)

	Hours
Engineering 7101–02, Advanced Kinetic Theory, Gasdynamics	6
Engineering 7201–02, Magnetohydrodynamics I and II	6
Engineering 7301–02, Fluid Mechanics I and II	6
Engineering 1171, 1172, Artificial Satellite Theory, Space Flight Mechanics	6

Electives: List A *

7103, Dynamics of Rarefied Gases	3
7104, Advanced Topics in High Temperature Gasdynamics	3
7203, Advanced Topics in Plasma Dynamics I	3
7204, Advanced Topics in Plasma Dynamics II	3
7303, Fluid Mechanics III	3
7304, Theory of Viscous Flows	3
7305, Hypersonic Flow Theory	3

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

Electives: List B

1162, Theory of Vibration	3
1163, Applied Elasticity	3
1164, Theory of Elasticity I	3
1165, Theory of Elasticity II	3
1167, Theory of Plate and Shell Structures	3
1170, Advanced Dynamics	3
1175, Oscillations in Nonlinear Mechanics	3
3652, Combustion Theory	3
3674, Statistical Thermodynamics	3
Physics 443, Atomic Physics and Introduction to Quantum Mechanics	3
Physics 444, Nuclear and High Energy Particle Physics	3
Physics 454, Introductory Solid State Physics	3
Physics 510, Advanced Experimental Physics	3
Physics 561, Theoretical Physics I	4
Physics 562, Theoretical Physics II	4
Physics 572, Quantum Mechanics	3
Physics 574, Intermediate Quantum Mechanics	3
Chemistry 580, Kinetics of Chemical Reactions	3
Chemistry 593, Quantum Mechanics	3
Chemistry 596, Statistical Mechanics	3
Chemistry 598, Molecular Spectra	3
EE 4531, Quantum Electronics I	3

	Hours
EE 4532, Quantum Electronics II	3
EE 4561, Plasma Physics I	3
EE 4562, Plasma Physics II	3
EE 4661, Kinetic Equations	3
EE 4662, Kinetic Theory of Plasmas	3

M.S. AND PH.D. DEGREES

To do original work in aerospace engineering in its broadest sense requires further advanced study in the graduate 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 fields 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 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

Riley-Robb Hall

Mr. O. C. French, Director; Messrs. R. D. Black, W. W. Gunkel, R. B. Furry, G. Levine, R. T. Lorenzen, D. C. Ludington, W. F. Millier, N. R. Scott, E. S. Shepardson, J. C. Siemens, J. W. Spencer.

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

The purpose of this curriculum is to prepare engineers for a career in one of the many industries and agencies that supply the great variety of products, machines, and services required by commercial farms, or those which process, handle, and distribute the products from farms.

Agricultural engineers are in great demand for design, research, development, and marketing of machines, structures, and systems that are vital for modern agricultural production.

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, 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 13 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 13 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	3	3	2½
Chemistry 103 or 107, General Chemistry...	3	2	3
or			
Chemistry 115, General Chemistry and Qualitative and Quantitative Analysis....	4	3	3
Freshman Humanities	3	–	–
Agr. Engineering 153, Engineering Drawing	3	2	3½
Agriculture 101, Orientation	1	1	0
Total	17–18		

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

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

TERM 3			
Mathematics 293, Engineering Mathematics	4	4	0
Physics 223, Introductory Analytical Physics	4	3	$2\frac{1}{2}$
Engineering 211, Mechanics of Rigid and Deformable Bodies	4	3	$2\frac{1}{2}$
Bio. Sciences 101, General Biology.........	3	3	3
or			
Bio. Sciences 103, Plant and Animal Biology	3	2	3
Chemistry 276, Introduction to Physical Chemistry	3	3	0
Total	18		

TERM 4			
Mathematics 294, Engineering Mathematics	3	3	0
Physics 224, Introductory Analytical Physics	4	3	$2\frac{1}{2}$
Engineering 212, Mechanics of Rigid and Deformable Bodies	4	3	$2\frac{1}{2}$
Bio. Sciences 102, General Biology	3	3	3
or			
Bio. Sciences 104, Plant and Animal Biology	3	2	3
Engineering 6211, Materials Science........	3	–	–
Total	17		

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

TERM 5	Credit Hours	Contact Hours Lec. Rec.	Lab. Comp.
Engineering 3621, Thermal Science I	3	3	0
Engineering 2301, Fluid Mechanics*	3	3	0
or			
Liberal Elective	3	–	–
Liberal Elective	3	–	–
Extension Teaching 301, Oral & Written Expression	2	–	–
Agr. Engineering 462, Agr. Power†	3	2	2½
Engineering 2701, Structural Theory†	3	2	2
Total	18		

TERM 6	Credit Hours	Lec. Rec.	Lab. Comp.
Engineering 3622, Thermal Science II	2	2	0
or			
Liberal Elective*	3	–	–
Liberal Elective	3	–	–
Agronomy 200, Nature and Properties of Soils	4	3	2½
Engineering 3331, Kinematics and Components of Machines	3	2	2½
Agr. Engineering 463, Processing & Handling Systems for Agr. Materials‡	4	3	2½
Agr. Engineering 481, Agr. Structures‡	3	2	2½
Total	18–19		

TERM 7	Credit Hours	Lec. Rec.	Lab. Comp.
Engineering 2301, Fluid Mechanics	3	3	0
or			
Engineering 2303, Hydrology*	2	2	0
Animal Science 100, or 112 or 250†	3–4	2–3	2½
Engineering 341, Electrical Engineering	3	2	2½
Agronomy 111, Field Crops†	4	3	2½
Liberal Elective	3	–	–
Elective	3	–	–
Total	17–19		

TERM 8	Credit Hours	Contact Hours Lec. Rec.	Lab. Comp.
Agr. Economics 302, Farm Management	5	3	2½
Engineering 342, Electrical Engineering	3	2	2½
Agr. Engineering 461, Agr. Machine Design‡	3	2	2½
Agr. Engineering 471, Soil and Water Engineering‡	3	2	2½
Agr. Engineering 450, Special Topics in Agr. Engineering	1	1	0
Liberal Elective	3	–	–
Total	18		
Total for eight terms	139–143		

* Students selecting more specialization in soils and water engineering would elect a sequence of Thermal Science 3621, Fluid Mechanics 2301, and Hydrology 2303. Others would elect a sequence of Thermal Science 3621, 3622 and Fluid Mechanics 2301.

† 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 481, Agr. Structures, are taken either in the sixth or eighth terms, alternating with Agr. Engineering 461, Agr. Machine Design, 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, primarily intended for students planning to enter professional practice. To be accepted as a candidate for this degree, an applicant must (1) hold a Bachelor's degree from an institution of recognized standing in one of the fields of engineering; (2) have a preparation adequate for graduate study in agricultural engineering; and (3) show promise of doing well in advanced study as judged by his previous scholastic record or other achievements.

Agricultural engineering electives will be selected to provide depth of preparation in one of the following areas: (a) power and machinery, (b) soils and water, and (c) agricultural structures and associated systems.

Engineering electives are to be chosen from subject areas relevant to agricultural engineering such as thermal engineering, mechanical design and analysis, theoretical and applied mechanics, structural engineering, hydraulics, soils engineering.

M.S. AND PH.D. 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, Cornell University.

BASIC STUDIES DIVISION

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 is responsible for admissions to the College at the underclass level, administers a program of courses for freshmen and sophomores, and assigns 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. Instruction in 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. If he does not express a particular interest, then 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. This makes possible more individual development toward a broader liberal program, or advanced technical study in line with the student's own inclination. Approximately one-fifth of the entering class is given advanced placement or actual college credit for one or more courses of the freshman year.

Superior students who have achieved two terms of advanced placement in mathematics and in 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 must be passed with an average of C or better, in order to remain in good standing in the Division. All engineering students are required to complete 24 hours of liberal studies before graduation; twelve hours of liberal electives must be completed by students in this Division as part of this College requirement. (See Liberal Studies in the Engineering Curricula, page 11, for distribution requirements.)

Freshman Year

Freshman students entering the College of Engineering in the fall of 1966 will take the following program of courses:

		Contact Hours	
FIRST TERM	*Credit Hours*	*Lect. Rec.*	*Lab. Comp.*
Mathematics 191, Calculus for Engineers...	4	3	2
Physics 121, Introductory Analytical Physics	3	3	2½
Chemistry 103 or 107, General Chemistry...	3	2	3
or			
Chemistry 115, General Chemistry and Inorganic Qualitative Analysis..........	4	3	3
Liberal Elective	3	3	0
Engineering 103, Engineering Graphics....	3	2	2½
or			
Engineering 104, Engineering Problems....	3	2	2½

SECOND TERM	*Contact Hours* Credit Hours	Lect. Rec.	Lab. Comp.
Mathematics 192 or 192H, Calculus for Engineers	4	3	2
Physics 122, Introductory Analytical Physics	3	3	2½
Chemistry 104, General Chemistry	3	2	3
or			
Chemistry 108, General Chemistry	4	3	3
or			
Chemistry 116, General Chemistry and Inorganic Qualitative Analysis	4	2	6
Liberal Elective	3	3	0
Engineering 103, Engineering Graphics	3	2	2½
or			
Engineering 104, Engineering Problems	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:

THIRD TERM			
Mathematics 293 or 293H, Engineering Mathematics	4	4	0
Physics 223 or 225, Introductory Analytical Physics	4	3	2½
Liberal Elective*	3 or 4	–	–
Engineering Sciences (two of following)	6 or 7	–	–
Physical Chemistry 276	(3)	(3)	(0)
Electrical Science 241	(3)	(2)	(2½)
Mechanics 211	(4)	(3)	(2½)

FOURTH TERM			
Mathematics 294 or 294H, Engineering Mathematics	3	3	0
Physics 224 or 226, Introductory Analytical Physics	4	3	2½
Liberal Elective*	3 or 4	–	–
Engineering Sciences (two of following)	6 or 7	–	–
Materials Science 6211	(3)	(2)	(2½)
Electrical Science 242	(3)	(2)	(2½)
Mechanics 212	(4)	(3)	(2½)

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 Physical Chemistry 276 — Materials Science 6211
Mechanical Engineering	Mechanics 211–212 Physical Chemistry 276 — Materials Science 6211
Engineering Physics	Electrical Science 241–242 Physical Chemistry 276 — Materials Science 6211
Materials Science and Engineering	Mechanics 211–212 Physical Chemistry 276 — Materials Science 6211
Electrical Engineering	Electrical Science 241–242 Mechanics 211–212
Industrial Engineering and Operations Research	Any two

Mechanics, electrical science, and physical chemistry 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; Physical Chemistry 276 and Materials Science 6210 in the fall and spring, and Materials Science 6210–6211 in the spring and summer. In 1966–67, Materials Science 6210 will be first offered in the spring of 1967.

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

THIRD TERM	*Credit Hours*	*Contact Hours* *Lect. Rec.*	*Contact Hours* *Lab. Comp.*
Mathematics 293 or 293H, Engineering Mathematics	4	4	0
Physics 223 or 225, Introductory Analytical Physics	4	3	2½
Chemistry 285, Introductory Physical Chemistry	5	4	6
Chemical Engineering 5101, Material and Energy Balances	3	3	2
Liberal Elective*	3 or 4	–	–

FOURTH TERM	Credit Hours	Contact Hours Lect. Rec.	Lab. Comp.
Mathematics 294 or 294H, Engineering Mathematics	3	3	0
Physics 224 or 226, Introductory Analytical Physics	4	3	2½
Chemistry 286, Introductory Physical Chemistry	5	4	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 24 credit hours are reserved for liberal studies, and at least 6 of the credit hours in upperclass courses. No more than 6 liberal credit hours may be earned in a modern foreign language.

In addition to the 24 credit hours for liberal studies, there are 6 credit hours for free electives. To satisfy this requirement, a student may take any course at the University to which he can gain admission.

CHEMICAL ENGINEERING

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. VonBerg, H. F. Wiegandt, R. York.

Chemical engineering involves the application of the principles of the physical sciences, 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 B.S. degree at the end of four years and the degree M. Eng. (Chemical) at the end of the fifth year is based on over 30 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 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 Term 1 through 4, administered by the Division of Basic Studies, are described on pages 32–35. 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 285, 286 and Engineering 5101, 5102 during the sophomore year.

The sequence of courses leading to the B.S. degree at the end of four years and the M. Eng. (Chemical) degree is given below.

BACHELOR OF SCIENCE

	Contact Hours		
	Credit Hours	Lect. Rec.	Lab. Comp.
TERM 5			
Chemistry 357, Introductory Organic Chemistry	5	3	6
Engineering 5303, Analysis of Stage Processes	3	2	2
Engineering 211, Mechanics	4	3	2½
Engineering 5851, Chemistry Microscopy	3 or 0	1	5
Liberal Elective	3 or 6	–	–
Total	18		
TERM 6			
Chemistry 358, Introductory Organic Chemistry	5	3	6
Engineering 5304, Introduction to Rate Processes	3	2	2
Engineering 5203, Chemical Processes	4	4	0
Engineering 212, Mechanics	4	3	2½
Engineering 5851, Chemical Microscopy	0 or 3	1	5
Liberal Electives	3 or 0	–	–
Total	19		
TERM 7			
Engineering 5103, Chemical Engineering Thermodynamics	3	2	2
Engineering 5353, Unit Operations Laboratory	3	2	3
Engineering 5255, Materials	4	4	0
Engineering 341, Electrical Engineering	3	3	0
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	19		
TERM 8			
Engineering 5104, Chemical Engineering Thermodynamics	3	2	2
Engineering 5354, Project Laboratory	3	1	5
Engineering 5256, Materials	3	3	0
Engineering 342, Electrical Engineering	3	3	0
Free Elective	3	–	–
Liberal Elective	3	–	–
Total	18		
Total for eight terms	142		

MASTER OF ENGINEERING (CHEMICAL)

TERM 9	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
Engineering 5621, Process Design and Economics	6	4	4
Engineering 5106, Reaction Kinetics	3	3	0
Technical Electives	6	–	–
Total	15		

TERM 10	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
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 7th and 8th terms and the nine credits of technical electives in the professional Master's degree program permit a student to select a maximum of 15 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 12, 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 required project-laboratory course. 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*	*Lect. Rec.*	*Lab. Comp.*
Engineering 5103, Chemical Engineering Thermodynamics	3	2	2
Engineering 5353, Unit Operations Laboratory	3	2	3
Engineering 5255, Materials	4	4	0
Engineering 5909, Research Seminar	0	1	0
Engineering 341, Electrical Engineering	3	3	0
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	19		

TERM 8			
Engineering 5104, Chemical Engineering Thermodynamics	3	2	2
Engineering 5952, Research Project	3	0	9
Engineering 5256, Materials	3	3	0
Engineering 342, Electrical Engineering	3	3	0
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	18		

TERM 9	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
Engineering 5106, Reaction Kinetics	3	3	0
Engineering 5631, Separation Processes	3	3	0
Engineering 5900, Seminar	1	1	0
Applied Mathematics	4	4	0
Minor Courses	3	–	–
Total	14		

TERM 10	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
Engineering 5717, Process Control	3	2	2½
Engineering 5632, Process Evaluation and Design	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), M.S., AND PH.D. 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 30 credit hours of specified courses as outlined on page 18. This Master of Engineering (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 30 credit hours. Cornell chemical engineering graduates who completed the five-year program leading to a B.Ch.E. degree prior to 1966, and who demonstrated aptitude for graduate work, may be awarded the Master of Engineering (Chemical) degree upon the successful completion of 15 additional credit hours as specified by the faculty of the School of Chemical Engineering and approved by the Graduate Programs Committee of the College of Engineering.

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.* 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

Hollister Hall

Mr. N. A. Christensen, Director; Messrs. V. C. Behn, D. J. Belcher, G. H. Blessis, W. Brutsaert, L. B. Dworsky, S. J. Errera, M. I. Esrig, G. P. Fisher, C. D. Gates, P. Gergely, W. H. Graf, D. J. Henkel, W. L. Hewitt, T. D. Lewis, T. Liang, J. A. Liggett, D. P. Loucks, W. R. Lynn, G. B. Lyon, W. McGuire, A. J. McNair, J. R. Morgali, A. H. Nilson, W. L. Richards, F. O. Slate, R. N. White, G. Winter, D. A. Woolhiser.

Civil engineering deals primarily with the large fixed works and facilities that are basic to community living, industry, and commerce. In a broad sense, the civil engineer controls and modifies our environment to satisfy the needs and desires of society. In doing so he deals with a wide variety of subfields. He is, for example, responsible for the design not only of the foundations and superstructures of our common structures such as buildings, bridges, dams, tunnels, wharves, etc., but also of unusual structures such as rocket installations, containment vessels for nuclear reactors, supports for radio telescopes, frames for aircraft, and also for devices used in other branches of engineering.

In addition, the civil engineer is concerned with the engineering aspects of water resources, rivers, harbors, irrigation, and drainage; with the disposal of wastes and the control of the quality of our air and water; with highways, railroads, pipelines, airports, and other transportation facilities; with measuring, mapping, and interpreting the physical conditions of the surface of the earth, often with the aid of electronic methods, photogrammetry, and aerial photographs; and with planning our metropolitan areas and constructing and managing their public facilities.

The work of the individual civil engineer may vary from conception, research, and development; to planning, design, construction, and operation; and it frequently involves helping to find solutions to complex social, political, economic, and managerial problems. Accordingly the profession requires the talents of those who are especially expert in one specialty as well as those who can coordinate the over-all efforts on large projects. All civil engineers should be well grounded in mathematics, science, and engineering technology, and all require a broad liberal education to enable them to be effective both as engineers and as citizens. They find employment in government, in private engineering practice, in the construction and manufacturing industries, in utility companies, in education, in sales, and in a variety of other areas.

Laboratory and Research Facilities

Modern, well equipped classrooms and laboratories are available for instruction and research in Hollister Hall, Thurston Hall, and in the Hydraulics Laboratory at Triphammer Falls. These facilities include several laboratories for testing models and full-scale structural assemblies; a concrete laboratory; two hydraulic laboratories; a highway materials and traffic engineering laboratory; sanitary chemistry and microbiology laboratories; a treatment processes laboratory; a soils engineering laboratory; laboratories for engineering analysis and interpretation of aerial photographs; and facilities for preparing maps and processing engineering data by photogrammetric methods. All of these are supported by a machine shop in Hollister Hall.

The Degree Programs

FIELD PROGRAM

The Civil Engineering Field Program includes course work in materials, hydraulics, soils, sanitary engineering, transportation, structures, construction engineering and administration, geodetic and photogrammetric engineering, and aerial photographic studies. In addition, two civil engineering electives permit the student to obtain additional work in a particular area.

To remain in good standing a student must maintain a grade point average of at least 2.0 each term.

The Bachelor of Science degree serves as one of the prerequisites for the M.S., Ph.D., or M.Eng. (Civil) Degrees.

BACHELOR OF SCIENCE

Civil Engineering Field Program Terms 1 through 4 are described on pages 31–35.

		Contact Hours	
TERM 5	*Credit Hours*	*Lect. Rec.*	*Lab. Comp.*
Geology 203, Geology for Engineers	3	2	2½
Engineering 9170, Industrial and Eng. Statistics	3	2	2½
Engineering 2701, Structural Engineering I	3	3	0
Engineering Science (Core Curriculum)	3	2	2½
Engineering Science (Core Curriculum)	3	3	–
Liberal Study (Core Curriculum)	3	–	–
Total	18		

	Contact Hours		
TERM 6	Credit Hours	Lect. Rec.	Lab. Comp.
Engineering 2001, Engineering Materials	3	2	2½
Engineering 2702, Structural Engineering II	3	2	2½
Engineering 2101, Engineering Measurements	3	2	2½
Engineering Science (Core Curriculum)	3	–	–
Engineering Science (Core Curriculum)	3	–	–
Liberal Study (Core Curriculum)	3	–	–
Total	18		

TERM 7			
Engineering 2703, Structural Engineering III	3	2	2½
Engineering 2401, Soils Engineering	3	2	2½
Engineering 2501, Water Supply and Waste-Water Engineering	3	3	–
Engineering 2302, Hydraulic Engineering	3	2	2½
Liberal Study or Free Elective (Core Curriculum)	3	–	–
Engineering 2601, Transportation Engineering	3	2	2½
Total	18		

TERM 8			
Civil Engineering Electives	6	–	–
Engineering 2903, Engineering Economy	3	3	–
Liberal Study* (Core Curriculum)	3 or 6	–	–
Free Electives† (Core Curriculum)	6 or 3	–	–
Total	18		

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

COLLEGE PROGRAM

As an alternative to the Field Program, the student may elect the *College Program* also leading to a Bachelor of Science Degree. A student with a strong interest in an interdisciplinary and/or specialized program may wish to consider the *College Program*. Where this involves one of the areas of Civil Engineering, either as a major or minor subject, the various Department Chairmen will be happy to discuss their offerings with the student. This degree also prepares the student for the M.S., Ph.D., or the M.Eng.(Civil) Degree, although the student who elects the *College Program* will ordinarily apply for the M.S. Degree.

GRADUATE STUDY

The School offers work leading to the degree of Master of Engineering (Civil), the M.S., and the Ph.D. degrees. In the field of civil engineering, the following areas of concentration are available either as major or minor subjects: geodetic and photogrammetric engineering, hydraulics, hydraulic engineering, construction engineering and administration, sanitary engineering, sanitary sciences, structural engineering, structural mechanics, soils engineering, transportation engineering, and aerial photographic studies. Descriptions of individual courses are given elsewhere in this Announcement.

The professional program is designed for students planning to enter the professional practice of engineering. The basic quantitative requirement is satisfactory completion of at least 30 credit hours of course work beyond the Cornell four-year program or 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. Graduate level project courses involving several of the following aspects of engineering are also included: feasibility, analysis, design, economics, and systems analysis. In addition, study related to the managerial phases of civil engineering is part of the basic 30 hour requirement.

Prospective graduate students should consult the *Announcement of the Graduate School.* A brochure, *Graduate Study in Civil Engineering,* may be obtained by writing the Graduate Field Representative, Civil Engineering, Hollister Hall.

COMPUTER SCIENCE (COLLEGES OF ENGINEERING AND OF ARTS AND SCIENCES)

Upson Hall

Mr. J. Hartmanis, Chairman; Messrs. K. M. Brown, R. W. Conway, P. C. Fischer, C. Pottle, G. Salton, S. Salzman, R. J. Walker.

Computer science is primarily the science of information. It 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 the organization of these units into efficient information processing systems.

In its various aspects, computer science is closely related to many other fields. The fundamental theory of information processing by mechanical means and the exploration of the limits of the abilities of computing machines are topics in pure and applied mathematics. Numerical analysis dealing with efficient computational procedures is also a part of applied mathematics. Computer science shares with electrical engineering an interest in the characteristics of physical machines and in computer design. It shares an interest in language structure and translation with linguistics. The implications of current data processing technology for the organization and control of industrial and business operations are also of interest in industrial engineering and in business administration.

Because of the wide implications of research in the field, the Department of Computer Science is organized as an intercollege department of the College of Engineering and the College of Arts and Sciences.

Computing Facilities

There are extensive computing facilities on the Cornell campus. The Cornell Computing Center has a Control Data 1604 and 160A available for faculty and student use with no outside commitments for these two computers. In addition, IBM 1401 and 1410 computers and an analog computer are operated elsewhere on the campus. An IBM 360/40 computer has been added recently, and in 1967 a large-scale remote-access, time-shared computing system will be installed.

The Degree Programs

In the Field of Computer Science, qualified graduate students can earn M.S. and Ph.D. 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. 12) to develop a course of study that provides an emphasis on computer science and related areas. 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, it is expected that they 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 and interact with their major field of study.

Graduate students in computer science can develop, with the assistance of the faculty of the Department of Computer Science, M.S. and Ph.D. degree programs to fit their interests. 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.

ELECTRICAL ENGINEERING

Phillips Hall

Faculty: H. J. Carlin, Director, Mr. J. L. Rosson, Assistant Director; Messrs. P. D. Ankrum, J. M. Ballantyne, R. Bolgiano, N. H. Bryant, G. C. Dalman, N. DeClaris, L. F. Eastman, W. H. Erickson, T. L. Fine, N. T. Gaarder, T. Gold, C. F. Green, C. E. Ingalls, F. Jelinek, M. Kim, K. R. Kleckner, R. L. Liboff, S. Linke, L. A. MacKenzie, H. S. McGaughan, P. R. McIsaac, C. W. Merriam, W. E. Meserve, S. K. Mitra, J. A. Nation, B. Nichols, R. E. Osborn, C. Pottle, E. L. Resler, Jr., G. C. Rumi, H. G. Smith, E. M. Strong, R. N. Sudan, C. L. Tang, J. S. Thorp, H. C. Torng, N. M. Vrana, L. S. Wagner, H. R. Witt, G. J. Wolga, S. W. Zimmerman.

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 18 of this announcement 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.*

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 Master of Engineering (Electrical), provides a sound foundation for him to practice electrical engineering successfully in a rapidly expanding field (that includes such recently developed areas as biomedical electronics, quantum electronics, plasma physics and magnetohydrodynamic power generation, space communication and control, computer design, and molecular electronics) and for engineering functions that range from research to production. 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 — and those in the process of development — 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 significantly greater depth and breadth than formerly. All undergraduate students enrolled in the E.E. Field Program are required to complete E.E. 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 E.E. 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 one of the areas or in neither. The curriculum contemplates an expansion of the time normally spent by the student in the laboratory. Each of the four laboratory courses involves two laboratory periods per week. There are sufficient time and flexibility to allow 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 E.E. 4321, 4322, 4421, and 4422 as a sequence of laboratory courses.

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 having an area of 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. There are also a number of laboratories located in Phillips

Hall devoted solely to graduate studies and research programs. Among these are laboratories for Systems Research, Control Systems, Analog Computers, Switching Circuits, Microwave Electronics, Physical and Solid State Electronics, Spectrophotometer, and for Illuminating Engineering Research. The Electric Energy Research Laboratory and the Radio Star Scintillation Laboratory are located in the vicinity of the University campus. 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*	*Lect. Rec.*	*Lab. Comp.*
Engineering 4301, Analysis of Electrical Systems I	4	3	2½
Engineering 4311, Electromagnetic Fields and Waves I	4	3	2½
Engineering 4321, Laboratory I	4	1	5
Engineering Science 231, Thermal Science†	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 II	4	3	2½
Engineering 4322, Laboratory II	4	1	5
Engineering Science 232, Fluid Mechanics†	3	3	–
Liberal Elective†	3	–	–
Total	18		

* Attention is called to the fact that change to a new curriculum is in progress. As a result the detailed curriculum may vary for each class.

TERM 7	Credit Hours	Contact Hours Lect. Rec.	Lab. Comp.
Engineering 4401, Signals in Linear Systems	4	3	2½
Engineering 4411, Quantum Theory	4	3	2½
Engineering 4421, Laboratory III	4	1	5
Liberal Elective†	3	–	–
Free Elective	3	–	–
Total	18		

TERM 8	Credit Hours	Contact Hours Lect. Rec.	Lab. Comp.
Engineering 4402, Random Signals in Linear Systems	4	3	2½
Engineering 4412, Solid State Physics	4	3	2½
Engineering 4422, Laboratory IV	4	1	5
Liberal Elective†	3	–	–
Free Elective	3	–	–
Total	18		

† The engineering science and liberal electives listed above are part of the Core Curriculum requirements described on page 11. Six hours of the engineering-science requirements are to be fulfilled by the required courses of the E.E. Field Program.

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 dropped from the School.

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.

For the elective courses listed in the electrical engineering section in the Description of Courses section of this Announcement, the digits in the four digit course number have significance as follows:

First digit: the 4 signifies that the course is taught in the School of Electrical Engineering.

Second digit: signifies the year-level of the course. Thus, a 4 means that the course may be taken by a student who is in his fourth year or beyond.

Third digit: signifies the course-group in which the course is considered to be assigned. Thus, a 3 means that the course is in the semiconductor and quantum electronics group.

Fourth digit: signifies the term in which the course is offered. If the digit is odd, the course is offered in the fall term; if even, the spring term. In general, a 0 means either term.

SEMICONDUCTOR AND QUANTUM ELECTRONICS

4531–32 Quantum Electronics
4533–34 Semiconductor Electronics
4535 Infrared and Optical Properties of Solids

POWER SYSTEMS AND MACHINERY

4441–42 Contemporary Electrical Machinery
4443 Power System Equipment
4444 High Voltage Phenomena
4543 Unified Theory of Electro-Mechanical Systems
4545–46 Electric Energy Systems

MICROWAVE AND PHYSICAL ELECTRONICS

4452 Introduction to Physical Electronics
4512 Fields, Waves, and Electrons
4551 Physical Electronics
4552 Microwave Electronics
4553 Microwave Electronics Laboratory
4554 Vacuum and Physical Electronics Laboratory
4653–54 Advanced Microwave Theory

WAVE PROPAGATION AND PLASMA PHYSICS

4461 Electromagnetic Theory
4462 Waves in the Atmosphere
4467 Radio Engineering
4511 Electrodynamics
4560 Radio and Communication Laboratory
4561–62 Plasma Physics
4565–66 Radiophysics of the Atmosphere
4567–68 Antennas and Radiation
4661 Kinetic Equations
4662 Kinetic Theory of Plasma

ELECTRICAL SYSTEMS

4501 Systems with Random Signals
4502 Statistical Aspects of Systems Analysis
4503 Theory of Linear Physical Systems
4504 Theory of Nonlinear Systems I
4505–06 Optimization and Approximation Techniques
4571 Network Theory
4572 Network Synthesis
4573–74 Random Processes in Electrical Systems
4581–82 Feedback Control Systems
4583 Analog Computation
4587–88 Switching Systems
4670 Advanced Topics in Electrical Systems
4671 Theory of Nonlinear Systems II

4673	Processing of Signals in Noise
4674	Transmission of Information
4681	Random Processes in Control Systems

Master of Engineering (Electrical)

The Master of Engineering degree is the only professional engineering degree offered by Cornell University. 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 Master of Engineering (Electrical) degree are:

1. A minimum total of 30 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 15 hours of credit for advanced courses taken during the fifth undergraduate year, provided they enter the Master of Engineering (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 15 credit hours of advanced standing, the requirement is six credit hours in the School of Electrical Engineering rather than two two-course sequences, and the design requirement may be waived.

M.S. AND PH.D. DEGREES

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

In the School of Electrical Engineering, research work leading to these degrees may be undertaken in the area of *electrophysics* including radio propagation, radio and radar astronomy, plasma physics, magnetohydrodynamics, physical and microwave electronics, materials science in electrical engineering, quantum electronics, 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, cognitive systems, etc. A number of fellowships, research assistantships, and teaching assistantships are available to candidates for the degrees of Master of Science and Doctor of Philosophy who are doing their thesis research in the School of Electrical Engineering. Assistantship applications and further information can be obtained by writing to the Coordinator of Graduate Studies, School of Electrical Engineering.

ENGINEERING PHYSICS

Rockefeller Hall

Mr. T. R. Cuykendall, Associate Director; Messrs. B. W. Batterman, K. B. Cady, D. D. Clark, D. R. Corson, E. T. Cranch, P. L. Hartman, J. P. Howe, J. A. Krumhansl, R. McPherson, M. S. Nelkin, H. F. Newhall, E. L. Resler, Jr., T. N. Rhodin, H. S. Sack, W. R. Sears, B. M. Siegel, J. Silcox, W. W. Webb, G. J. Wolga.

Creativity and innovation in engineering and applied science depend significantly on basic and advanced knowledge in physics and applied mathematics and on the techniques of applying this knowledge to engineering problems. Accordingly the engineering physics program provides this kind of knowledge, encourages this approach among students with an interest and competence for such areas. It seeks to prepare students for the continually widening engineering challenges that have deepening roots in fundamental knowledge 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 "fifth 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 activities of the department are housed in Rockefeller and Clark Halls, which are connected and which also house the Department of Physics, and in the Nuclear Reactor Laboratory. Rockefeller Hall is the center for undergraduate affairs, such as student advising. Graduate activities and research are under way in all three buildings.

The department is fully equipped 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.

Five commercial electron microscopes are in use in the department. Ultra high resolution instruments for atomic and molecular microscopy are being developed. Super-conducting and magnetic phenomena are being studied at very low temperatures. Apparatus and equipment for studying nuclear phenomena are extensive and are described on page 77.

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 stage and further progress is obvious.

While students may enroll in the Engineering Physics program from the non-honors sections of physics and math, registration in honor sections is very desirable and strongly recommended.

Initiation of the study of a specialty is encouraged through courses such as Physcis 444, Nuclear Physics, or Engineering 8303, Nuclear and Reactor Physics, Physics 454, Solid State Physics, and additional topics in Physics 410, Advanced Physics Laboratory.

By suitable selection of technical electives during his last year the qualified student may prepare for a career in one of the many specialized fields of engineering. As examples, four possible programs are outlined:

AEROSPACE ENGINEERING (see page 23). The undergraduate program in engineering physics is particularly suited for work in aerospace engineering either at the undergraduate or at the graduate level.

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, 6872, and 7201, which are described in detail in the section, "Description of Courses." 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 engineering physics (e.g., 8262, 8512), materials and metallurgy, and with 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.

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 better, and to demonstrate aptitude and competence in the basic subject matter of the curriculum.

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

BACHELOR OF SCIENCE

The Bachelor of Science in engineering and preparation for graduate work in the Fields mentioned above may be obtained by satisfactorily completing the following curriculum or its equivalent. (Terms 1 through 4 are described on pages 31–35).

		Contact Hours	
	Credit	*Lect.*	*Lab.*
TERM 5	*Hours*	*Rec.*	*Comp.*
Math 421, Applied Mathematics	4	4	0
Physics 337M, Electromagnetic Field Theory	3	3	0
Engineering 8133, Physical Mechanics I	3	3	0
Engineering 4301, Passive Electrical Systems	4	3	1
Engineering, Electrical Laboratory	1	0	1
Liberal Elective	3 or 4	–	–
Total	18 or 19		

TERM 6	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
Math 422, Applied Mathematics	4	4	0
Physics, Field Theory, Cont'd.	3	3	0
Engineering 8134, Physical Mechanics	3	3	0
Engineering 4302, Active Systems	4	3	1
Engineering, Electrical Laboratory	1	0	1
Liberal Elective	3 or 4	–	–
Total	18 or 19		

TERM 7	Credit Hours	Lect. Rec.	Lab. Comp.
Mathematics 423, Applied Mathematics	4	4	0
Physics 443, Atomic Physics and Introduction to Quantum Mechanics	3	3	0
Engineering 8121, Thermodynamics and Fluid Mechanics	3	3	0
Free Elective	3	–	–
Liberal Elective	3 or 4	–	–
Total	17 or 18		

TERM 8	Credit Hours	Lect. Rec.	Lab. Comp.
Physics 444, Nuclear or High Energy Particle Physics	4	4	0
or			
Physics 454, Solid State Physics			
or			
Engineering 8309, Low Energy Nuclear Physics	3	0	0
Physics 410, Advanced Experimental Physics	4	1	6
Engineering 8122, Thermodynamics and Fluid Mechanics	3	3	0
Free Elective	3	0	0
Liberal Elective	3 or 4	0	0
Total	17 or 18		

THE COLLEGE PROGRAM

The *College Program* (see pp. 12–13), 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 must be approved after formulation by the student and cannot be specified in approved form in advance. Some partial course combinations of possible interest are:

MAJOR IN NUCLEAR ENGINEERING

Physics 436, Modern Physics
Engineering 8303, Introduction to Nuclear Engineering
Engineering 8351, Nuclear Measurements Laboratory
Engineering 5760, Nuclear and Reactor Engineering
Engineering 8336, Nuclear Materials

MINOR IN NUCLEAR ENGINEERING

Physics 436, Modern Physics
Engineering 8303, Nuclear and Reactor Physics
and either
Engineering 8351, Nuclear Measurements Laboratory
or
Engineering 8336, Nuclear Materials

MAJOR IN ENGINEERING PHYSICS

Physics 337, Intermediate Analytical Physics I
Physics 338, Intermediate Analytical Physics II
Physics 443, Atomic Physics and Introduction to Quantum Mechanics
Physics 410, Advanced Experimental Physics

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.

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

Admissions Requirements

1. For Cornell students: A grade point average of 2.5 or better 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 taken from a list to be drawn up 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 380, 596 or a new equivalent course to be arranged.
6. A one-hour seminar course — a modified version of 8252.
7. Technical electives to bring the total credit hours to 30.

MASTER OF ENGINEERING (NUCLEAR)

This program is described elsewhere in the Announcement, see p. 77.

M.S. AND PH.D. DEGREES IN APPLIED PHYSICS

The faculty of the Department of Engineering Physics is associated with the Field of Applied Physics in the Graduate School. The objectives and nature of this Field are an extension of those of the undergraduate program into the realm of original research. They are described in the *Announcement of the Graduate School.* Major purposes are to afford creative students with a background in physics the opportunity to carry their training to the point of making original applications and to allow students with originality and training in engineering to acquire a deep knowledge of physics.

Examples of research studies now under way, using facilities mentioned earlier, are: development of an electron microscope system capable of resolving approximately 2×10^{-8} cm; application of electron microscopy to biologically important molecules and structures; use of electron scattering and optics in the study of the magnetic structure of superconducting and magnetic solids; structure of substances near the critical temperature; use of low energy electron diffraction and field ion microscopy in the study of atomic arrangements and reactions on the surface of solids; effects of high energy radiation on solids; and theory of the dynamical behavior of liquids. Through association with faculty from other departments, topics such as lasers, plasma dynamics, theory of solids, and theoretical mechanics may be pursued.

Requisites for entering graduate study in the Field of Applied Physics may be found in the *Announcement of the Graduate School,* which also lists opportunities for financial support. Applications and detailed information may be obtained from the Field Representative, Applied Physics. Department of Engineering Physics, Rockefeller Hall. A descriptive booklet is available upon request.

Courses of study for the degree are not prescribed, and the Graduate School imposes few specific subject requirements. Individual programs of formal or informal study are arranged by a student and a special committee of his own selection.

ENVIRONMENTAL SYSTEMS ENGINEERING

Hollister Hall

Mr. G. P. Fisher, Chairman; Messrs. G. H. Blessis, L. M. Falkson, T. D. Lewis, W. R. Lynn, W. L. Richards.

Environmental systems engineering is a new activity which has as its main thrust the substantive application of operations research and systems analysis to problems, predominantly civil engineering in character. Its particular areas of concern are transportation systems; construction systems; air, water, and other natural systems; structural systems, especially optimization and automated design. Working relationships are maintained with the Department of Industrial Engineering and Operations Research, and with the Department of Urban and Regional Planning (College of Architecture), in addition to the other departments of the School of Civil Engineering.

Substantial effort is directed to the treatment of large-scale problems such as total transportation systems, river basin studies, rationalization of complex construction projects, and on associated land use patterns and land values. The economics, planning, and management of both man-made and natural environment, and the associated decision-making process are stressed.

Undergraduate education in this area is normally carried on within the framework of the School of Civil Engineering (see pp. 41–43). *Graduate studies,* particularly in transportation engineering and in construction engineering and management, are conducted primarily within the framework of the Department of Environmental Systems Engineering. Graduate studies in water resource systems are undertaken cooperatively with the areas of hydraulics and sanitary engineering. Candidates for advanced degrees are considered with undergraduate or graduate work in any area of civil engineering, in operations research, industrial engineering, and in economics.

Prospective graduate students should communicate with the chairman, Department of Environmental Systems Engineering, Hollister Hall, for information regarding graduate programs in Environmental Systems Engineering.

INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

Upson Hall

Mr. B. W. Saunders, Director; Messrs. R. N. Allen, R. E. Bechhofer, R. H. Bernhard, R. W. Conway, J. P. Evans, H. P. Goode, D. L. Iglehart, K. O. Kortanek, W. L. Maxwell, N. U. Prabhu, S. Saltzman, M. W. Sampson, A. Schultz, Jr., H. M. Taylor III, L. I. Weiss.

Industrial engineering involves 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 may have a number of common characteristics which make them typical industrial engineering problems. For example, the determination of the number of toll booths which should be placed at the entrance to a turnpike or tollbridge, the type of maintenance system to be used in a mass production plant, the design of a telephone system to handle customers in a sales office, and the policies to be followed in assignment of runways at a busy airport all seem to be very different problems. Yet every one of them involves a facility of some sort which provides service to a series of inputs or customers. This identifies it as a queuing problem which may be analyzed with well known industrial engineering techniques involving, in some cases, mathematical theory and models and the utilization of a digital computer.

Another group of operating systems which have common characteristics would include such things as the design of an inventory control system for a manufacturing organization, determination of the size of an airplane to use on a particular run, establishing a replacement policy for production machines, and planning what volume of foods to purchase for a busy restaurant. These problems involve the stocking of commodities for which the demand is uncertain. In each case the cost of securing and holding an item is balanced against the level of service to be provided. These characteristics identify these problems as ones involving inventory theory, and they can be analyzed using the techniques which have been developed for inventory problems.

Prior to 1950 nearly all industrial engineering work took place in the mechanical manufacturing industries. Today, developments in the field have been so extensive that analytical methods and design techniques used by industrial engineers are as applicable in service industries, government, and institutional operations as they are in manufacturing. Indeed, the scope of work has tended to outgrow the designation "industrial engineering," and this type of work often is identified by other names. Many schools and organizations use "operations research" to cover approximately the same activity. Other terms frequently used include "operations analysis," "systems analysis," "systems engineering," and "management science." It is not meant to imply that these names are all completely synonomous, but rather that there is a high degree of overlap in the areas covered by terms for which there is no universally accepted meaning, and which are used by different individuals and groups in quite different ways. "Industrial engineering" is used at Cornell because here the emphasis is on both the analysis and synthesis leading to the design of the facilities and procedures necessary to make an efficient operating system serving some needed function.

Following the first two years of work in the Division of Basic Studies, the curriculum leading to the professional degree in industrial engineering, Master of Engineering (Industrial), develops the necessary background in probability, statistics, computing, and cost analysis in the third year and goes into considerable depth in analysis, design, model building, and experimental methods in the fourth year. Students satisfactorily completing the work of these four years are awarded a Bachelor of Science degree. Qualified candidates may then continue with the fifth year of study which includes a two-term project and a number of applied analytical courses which are closely integrated with the work of the previous four years. The required courses coupled with a well-planned elective program permit the student to develop a course of study of considerable breadth or depth to suit his own interests and needs.

Laboratories and Research Facilities

The program in industrial engineering is under the direction of the Department of Industrial Engineering and Operations Research, with offices and class rooms in Upson Hall. Facilities include some conference-type class and seminar rooms, a methods laboratory, and computing rooms containing adding machines and desk calculators. It should be noted also that 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 (described on p. 45). As mentioned elsewhere, every engineering student at Cornell learns how to program problems for the computer in his freshman year. Students in industrial engineering 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 addition, term projects, graduate theses, and a considerable amount of departmental research utilize computer time to the extent that 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 pp. 31–35 of this *Announcement*. The DBS 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, 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 more complete preparation to that point.

TERMS 1–4

See Division of Basic Studies Curriculum on pp. 31–35.

TERM 5	Credit Hours	Contact Hours Lect. Rec.	Lab. Comp.
Engineering Science*	3	–	–
Engineering 231, Thermal Science I†	3	3	–
Engineering 9301, Introduction to Industrial Engineering	1	1½	–
Engineering 9350, Cost Analysis and Control	4	3	2½
Engineering 9360, Probability Theory	4	3	2½
Liberal Elective	3	3	–
Total	18		

TERM 6	Credit Hours	Lect. Rec.	Lab. Comp.
Engineering Science*	3	–	–
Engineering 232, Thermal Science II†	3	3	–
Engineering 9302, Manufacturing Problems	2	–	3½
Engineering 9370, Statistical Theory	4	3	2½
Engineering 9381, Introduction to Computer Science	3	2	2½
Liberal Elective	3	3	–
Total	18		

TERM 7	Credit Hours	Lect. Rec.	Lab. Comp.
Engineering 9310, Industrial Engineering Analysis	4	3	2½
Engineering 9320, Industrial Engineering Models	4	3	2½
Technical Elective	3	–	–
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	17		

* This will be the third engineering science course mentioned above and not taken in the second year. It will generally be Electrical Engineering 341–342.

† Thermal science is the fourth in the sequence of the required engineering science courses. This course will not be available in the sophomore year in 1966–67, hence is listed explicitly as a third year course.

Note that students are permitted to take four-credit hour elective courses in place of three-credit hour courses where they so desire.

TERM 8	Credit Hours	Contact Hours: Lect. Rec.	Contact Hours: Lab. Comp.
Engineering 9303, Industrial Engineering Laboratory	4	2	5
Engineering 9311, Industrial Engineering Design	4	2	5
Technical Elective	3	–	–
Liberal Elective	3	–	–
Free Elective	3	–	–
Total	17		

Scholastic Requirements

A student in the Department 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 requirements, may be dropped or placed on probation.

Elective Courses

The industrial engineering curriculum is specifically designed to provide in its elective content considerable flexibility in both technical and liberal courses. It includes a minimum of 30 elective credit hours (including 6 hours taken in the Division of Basic Studies) divided into 18 liberal, 6 technical and 6 free. This permits students with widely varying interests to develop programs which meet their own needs. For example, the student may utilize the 6 technical and 6 free electives to take 12 hours of work in one technical area. This may be in industrial engineering or it may be in another engineering field. For illustration: a student might take a concentration of courses in machine design (mechanical engineering), in sanitary engineering (civil engineering), or in the systems sequence of electrical engineering. That is possible and logical because the analytical methods of industrial engineering lend themselves to work in virtually every engineering field as demonstrated by the very wide variety of jobs presently held by industrial engineering graduates. Many other possibilities exist.

These same hours when properly planned can be very effectively used to reduce the time required for graduate study in other fields such as Business and Public Administration or City and Regional Planning. These opportunities, described more explicitly in the following section on graduate study, are made possible because the analytical methods used in industrial engineering are relevant to problems found in these other fields.

MASTER OF ENGINEERING (INDUSTRIAL)

The professional Master of Engineering (Industrial) degree program is designed for those primarily interested in becoming proficient in the practice of modern industrial engineering. This is a formal "course" program which concentrates on additional analytical and design techniques with special emphasis on their application. Details of the program are shown below. To be accepted as a candidate for the Master of Engineering degree, an applicant must (1) hold a Bachelor's degree from an institution of recognized standing in one of the fields of engineering; (2) have an adequate preparation for graduate study in industrial engineering; and (3) show promise of doing well in advanced study as judged by his previous scholastic record or other achievements.

		Contact Hours	
FALL TERM	*Credit Hours*	*Lect. Rec.*	*Lab. Comp.*
Engineering 9526, Mathematical Models	4	3	2½
Engineering 9580, Systems Simulation	4	3	–
Engineering 9598, Project	2	As arranged	
Design Course (Selected from I.E. or other approved engineering design courses)	3	Varies with course	
Professional Elective	3	Varies with course	
Total	16		

		Contact Hours	
SPRING TERM	*Credit Hours*	*Lect. Rec.*	*Lab. Comp.*
Engineering 9551, Advanced Engineering Economic Analysis	3	3	–
Engineering 9521, Production Planning and Control	4	3	2½
Engineering 9599, Project	4	As arranged	
Professional Elective	3	–	–
Total	14		

M.S. AND PH.D. DEGREES

The Master of Science and Doctor of Philosophy programs are designed for those primarily interested in academic or industrial research and in teaching. A student matriculating for one of these degrees may concentrate his studies in any one of several subjects such as industrial engineering, operations research, systems analysis and design, applied probability and statistics, and information processing. To be accepted as a candidate for the Master of Science or Doctor of Philosophy degree in one of the subjects of concentration, the applicant must have been graduated from an institution of recognized standing with a Bachelor's degree in engineering, mathematics, or the physical sciences. In addition he must have had a superior undergraduate scholastic record as evidence of his ability to pursue advanced study and research in the selected field. In case any doubt exists that these requirements are not all met, it is suggested that the student take the Graduate Record Examination of the Educational Testing Service and have the results sent to Cornell.

These graduate programs rely heavily on the very extensive academic resources of the University. The presence on the campus of the professional Schools of Business and Public Administration, Industrial and Labor Relations, and of City and Regional Planning as well as such departments in the College of Arts and Sciences as mathematics, economics, psychology, and sociology provide students with an extremely wide range of courses from which to draw. For example, one doctoral candidate might have a major concentration in systems analysis and design and select his minor concentrations in mathematics and econometrics while another might build a program combining industrial engineering, psychology, and applied statistics.

For further information about each of these graduate programs a brochure, *Graduate Study in Industrial Engineering and Operations Research,* may be obtained by writing to the Director of the Department of Industrial Engineering and Operations Research, Upson Hall.

OTHER PROFESSIONAL GRADUATE PROGRAMS OF SPECIAL INTEREST TO INDUSTRIAL ENGINEERS

The undergraduate curriculum in the Field of Industrial Engineering provides a very sound base for two other professional Master's degree programs available at Cornell. One, the Master of Regional Planning (M.R.P.), is offered by the Department of City and Regional Planning of the College of Architecture and is described in detail in the Announcement of that College. By proper selection of elective courses coupled with the required courses in industrial engineering, it should be possible to complete this program in three additional terms beyond the B.S. degree. This field is particularly challenging, and is one in which industrial engineering methodology, applicable in dealing with large scale systems problems, has special relevance.

Another professional program of special interest is one leading to the Master of Business Administration (M.B.A.) degree offered by the Graduate School of Business and Public Administration, described in the Announcement of that School. By proper selection of elective courses and by completing the proper steps in admissions during the third year, the student may obtain the M.B.A. degree in one additional year beyond the B.S. program in contrast to the two additional years normally required for students in other engineering, science, or liberal arts programs.

The two professional programs mentioned above, plus the professional program in engineering (M.Eng.) and the research degree (M.S.), make four Master's degree programs readily available to qualified students who select the field of industrial engineering as their undergraduate area of concentration and, in two cases, the Master's degree can be earned in less time than if some other fields of concentration were chosen. In all cases where the student is contemplating graduate study, he should discuss this with his adviser and with the admissions officer of the unit in which he intends to do his graduate work, not later than the start of his sixth term at Cornell.

MATERIALS SCIENCE AND ENGINEERING

Bard Hall

Mr. W. S. Owen, Director; Mr. M. S. Burton, Assistant Director; Messrs. R. W. Balluffi, B. W. Batterman, J. M. Blakely, J. L. Gregg, J. O. Jeffrey, H. H. Johnson, C. Y. Li, A. L. Ruoff, E. Scala, D. N. Seidman, G. V. Smith, A. Taylor.

Materials science is a new discipline which relates the principles of physics and chemistry to materials, while materials engineering has developed during the past several years principally from metallurgical engineering. This evolution has been hastened by rapid and extensive developments in non-metallic materials. Modern engineering requires new and improved materials having properties well beyond those attainable with common metals and alloys. Thus, further understanding of the nature of materials and control of their properties has become a vital factor in the development and selection of materials. Empirical approaches have been replaced by theoretical and analytical treatments of materials and their properties, as the art of metallurgy has become the science of materials. Selection, processing, and application of materials for specific needs has become materials engineering.

Laboratory and Research Facilities

The Materials Science and Engineering Department is centered in Bard Hall, and, in addition, occupies portions 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 measurements, microscopy, metallography, and x-ray diffraction are available. Equipment for processing materials by casting, welding, heat treatment, compacting and sintering, deformation, and for many of the newer processing procedures are included. Laboratories for preparing and studying non-metallic 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, effects of high pressure on materials; and service facilities for producing, characterizing, and testing various metallic and non-metallic materials.

The Degree Programs

At Cornell, the materials science and engineering curriculum provides mathematics, physics, chemistry, and engineering sciences that are fundamental to effective work in materials science and materials engineering. The basic work on materials is continued in the required courses. These include discussions of crystallographic and other structural aspects of materials, mechanical behavior, phase transformations and their kinetics, and electrical and magnetic properties of materials. By suitable choice of electives, there is considerable flexibility within the curriculum.

However, it has been found convenient to define *two* general course programs, one containing a greater emphasis on the engineering applications of materials science than does the other. The materials science and engineering program contains required courses in the chemical and mechanical aspects of materials processing, whereas the materials science alternative emphasizes the scientific basis of the subject by providing different courses in mathematics and solid state physics. It is usually advisable for students taking the materials science option to elect at least one of the two courses in materials processing.

All able 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.

While the materials science option provides the better basis for starting research in some of the areas currently active in the Department, there is also much research activity with a substantial engineering emphasis. Thus, either program can be a good preparation for graduate study.

BACHELOR OF SCIENCE

Course programs for Terms 1–4, administered by the Division of Basic Studies, are described on pages 31–35.

MATERIALS SCIENCE AND ENGINEERING PROGRAM

		Contact Hours	
	Credit	*Lect.*	*Lab.*
TERM 5	*Hours*	*Rec.*	*Comp.*
Engineering 6031, Structure of Materials	3	3	0
Engineering 6033, Structure of Materials Laboratory I	2	0	3
Engineering 6035, Thermodynamics and Fluid Mechanics	3	3	0
Engineering 241, Electrical Science, —or— Engineering 243, Electrical Engineering ‡	3	2	2½
Free Elective	3	–	–
Liberal Elective	3–4*	–	–

TERM 6	Credit Hours	Contact Hours Lect. Rec.	Contact Hours Lab. Comp.
Engineering 6032, Mechanical Properties of Materials	3	3	0
Engineering 6034, Structure of Materials Laboratory II	2	0	3
Engineering 6036, Thermodynamics and Fluids	3	3	0
Engineering 242, Electrical Science, —or— Engineering 244, Electrical Engineering ‡	3	2	2½
Free Elective	3	–	–
Liberal Elective	3–4*	–	–

TERM 7	Credit Hours	Lect. Rec.	Lab. Comp.
Engineering 6041, Kinetics	3	3	0
Engineering 6043, Senior Laboratory I	3–4†	0	5
Engineering 6045, Materials Processing I (Mechanical)	3	3	0
Free Elective	3	–	–
Liberal Elective	3–4*	–	–

TERM 8	Credit Hours	Lect. Rec.	Lab. Comp.
Engineering 6042, Electrical and Magnetic Properties of Materials	3	3	0
Engineering 6044, Senior 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 in 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 Engr. 241, 242 as sophomores will register for Engr. 211, 212.

MATERIALS SCIENCE PROGRAM

	Contact Hours		
	Credit Hours	*Lect. Rec.*	*Lab. Comp.*
TERM 5			
Engineering 6031, Structure of Materials	3	3	0
Engineering 6033, Structure of Materials Laboratory I	2	0	3
Engineering 6035, Thermodynamics and Fluid Mechanics	3	3	0
Physics 337, Intermediate Analytical Physics	4	3	2½
Engineering 1150, Advanced Engineering Mathematics I	3	3	0
Liberal Elective	3–4*	–	–
TERM 6			
Engineering 6032, Mechanical Properties of Materials	3	3	0
Engineering 6034, Structure of Materials Laboratory II	2	0	3
Engineering 6036, Thermodynamics and Fluids	3	3	0
Physics 360, Introductory Electronics	4	3	2½
Engineering 1151, Advanced Engineering Mathematics II	3	3	0
Liberal Elective	3–4*	–	–
TERM 7			
Engineering 6041, Kinetics	3	3	0
Engineering 6043, Senior Laboratory I	3–4†	0	5
Physics 443, Atomic Physics and Introduction to Quantum Mechanics	4	4	0
Liberal Elective	3–4*	–	–
Free Elective	3–4‡	–	–
TERM 8			
Engineering 6042, Electrical and Magnetic Properties of Materials	3	3	0
Engineering 6044, Senior 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 in 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 are advised to elect the Materials Processing courses Engr. 6045, 6046.

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 having special interests, either within the field or in other divisions of the College or University, to plan educational programs that closely parallel 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 6669, Introductory Physical Ceramics
Engineering 6872, Nuclear Materials
Engineering 8302, Nuclear and Reactor Physics

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 Engineering 6211, Materials Science; and Engineering 6031, Structure of Materials. 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 pps. 12–14 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 the Master of Engineering (Materials) program. The course of study can be completed in one academic year by students whose undergraduate training is in metallurgy, metallurgical engineering, or materials; one additional term is necessary for most students having other undergraduate preparation.

	Contact Hours		
TERM 9	Credit Hours	Lect. Rec.	Lab. Comp.
Engineering 6551, Production of Metals and Ceramics	3	3	0
Engineering 6553, Project	3	0	9
Engineering 6503, Materials Selection and Use	3	3	0
Technical Elective	3	–	–
Graduate Core Course*	3	–	–
TERM 10			
Engineering 6552, Materials Engineering	3	3	0
Engineering 6554, Project	3	0	9
Engineering 6555, Materials Processing	3	3	0
Technical Elective	3	–	–
Graduate Core Course*	3	–	–

* Selected from courses 6601, 6602, 6603, 6604, 6605, 6606, 6611.

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 in a multitude of engineering systems. Metallic and non-metallic materials, as well as some aspects of the liquid state, are incorporated into a common framework of instruction.

Graduate programs lead to the degrees of Master of Engineering (Materials), Master of Science, and Doctor of Philosophy. The M.S. and Ph.D. programs are primarily science-oriented courses of study and research, which are 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.*

The Field faculty usually requires that a student who enters with an undergraduate degree and desires to work toward the Ph.D. first register as a candidate for the M.S. 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 recommended for admission to candidacy for the Ph.D. degree. If he wishes, the student may then proceed directly to the Ph.D. without taking the M.S. 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 materials behavior at an advanced level, including such topics as imperfections; nucleation theory; phase transformations; electric, magnetic and mechanical properties of solids; lattice dynamics; phase equilibria, rate processes.

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

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

MECHANICAL ENGINEERING

Upson Hall

Mr. D. G. Shepherd, Director; Mr. G. R. Hanselman, Assistant Director; Messrs. N. W. Abrahams, T. J. Baird, J. F. Barrows, J. F. Booker, A. H. Burr, B. J. Conta, T. A. Cool, D. Dropkin, G. B. DuBois, F. S. Erdman, H. N. Fairchild, B. Gebhart, R. L. Geer, S. Leibovich, A. W. Luce, H. N. McManus, Jr., F. K. Moore, F. W. Ocvirk, R. M. Phelan, R. L. Wehe.

Mechanical Engineering is the broadest of the several fields of engineering and the curriculum is designed to provide this breadth of training. Mechanical engineers are involved in two major streams of technology: one in the production and utilization of energy and the other in the design and production of goods, machines, equipment and systems. They are concerned with conversion between mechanical, thermal, nuclear and electrical energy; the uses of energy in transportation by land, sea and air, and in space; the control of the environment at the surface of the earth and the provision of environments suitable for human activity deep in the ocean and far out in space; the design of mechanical components and systems to accomplish these and other ends, together with their manufacture, distribution and use. They are necessarily involved with materials, materials processing and materials handling, and may work with scientists and engineers in many fields. They are concerned not only with design for function but design for economic ends. They may engage in technical sales work, and mechanical engineers very frequently become part of management as their experience increases.

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 earlier courses in the program necessarily tend toward separate treatment of a particular subject, but the later courses, particularly some in the fourth year, are more integrated to show the interrelation of the many fields of study making up mechanical engineering. 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 taken further, together with the opportunity to undertake 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, with *technical elective* meaning 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.

While 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, College and School 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 program of a professional nature, intended for those students who wish to practice mechanical engineering. While 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 2) or not changing their field for advanced work (see 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.*

3. *Graduate study in related fields,* such as Aerospace Engineering, Industrial Engineering or Nuclear Engineering, for example, or in different fields such as Business Administration or Law.

Laboratory and Research Facilities

The thermal engineering and machine design laboratories are located in Upson Hall; materials processing laboratories are in Kimball Hall.

In the thermal engineering area, modern instrumentation and techniques are used for regular instruction in the steady and transient state measurement of temperature, heat flow and properties of flowing fluids. The laboratories are equipped with precision potentiometers, pressure transducers, oscilloscopes, oscillographs, hot-wire anemometers, etc. Considerable use is made of visualization equipment, such as shadowgraph and schlieren apparatus, flow models, and films. In several courses, the services of the Cornell Computing Center are employed as a necessary adjunct to modern mechanical engineering.

The Department of Machine Design has its own laboratories for stress, 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.

The Degree Programs

The undergraduate program in Mechanical Engineering leads to a Bachelor of Science (B.S.) degree upon the successful completion of a four-year curriculum. The minimum number of credit hours required is 135.

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 31–35). 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; *physical chemistry-materials science* is recommended for the second sequence, but is not required.

In the junior and senior years, 54 credit hours of technical courses related to mechanical engineering are required. These include courses in the Mechanical Engineering Departments of Thermal Engineering, Machine Design, and Materials Processing, plus specified courses in the Departments of Industrial Engineering and Operations Research and of Materials Science and Engineering. In addition, 18 credit hours of liberal and unrestricted electives are required. *Unrestricted electives* may be any courses in the University to which the student can gain admission, including 6 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 15 credit hours, with a grade of C— (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 less than fifteen credit hours per term.

BACHELOR OF SCIENCE

TERMS 1–4

See Division of Basic Studies Curriculum (pp. 31–35).

		Contact Hours	
TERM 5	*Credit Hours*	*Lect. Rec.*	*Lab. Comp.*
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
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			
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
Liberal Elective*	3 or 4	–	–
Total	18 or 19		

TERM 7	Credit Hours	Contact Hours Lect. Rec.	Lab. Comp.
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		

TERM 8	Credit Hours	Lect. Rec.	Lab. Comp.
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 11 for definition of liberal electives.

MASTER OF ENGINEERING (MECHANICAL)

The degree of Master of Engineering (Mechanical) is available as a curricular type of professional degree, the general requirements for which are stated on page 18. Of the 30 credit hours required, the Mechanical Engineering program allows 9 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, Master of Engineering (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, the *mathematics requirement* may be satisfied by Mathematics 315, 316, or Applied Mathematics 1150, 1151 or 1180, 1181, or other approved courses. 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, 21 hours of the 30-hour requirement are, to a large extent, elective. In this way, the student has wide latitude to obtain a specific educational objective.

MASTER OF ENGINEERING (MECHANICAL), M.S., AND PH.D. DEGREES

Graduate education in engineering becomes more and more desirable each year to gain adequate preparation for careers in engineering practice, research, or teaching. Graduate programs are available in mechanical engineering leading to the degrees of Master of Engineering (Mechanical), Master of Science, and Doctor of Philosophy.

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

A brochure, *Graduate Study in Mechanical Engineering,* may be obtained by writing to the Director, Sibley School of Mechanical Engineering, Upson Hall.

NUCLEAR SCIENCE AND ENGINEERING (GRADUATE PROGRAM)

Nuclear Reactor Laboratory

Members of Graduate Field of Nuclear Science and Engineering. Faculty: K. B. Cady, D. D. Clark, T. R. Cuykendall, D. Dropkin, C. D. Gates, J. L. Gregg, J. P. Howe, S. Linke, R. M. Littauer, R. E. McPherson, W. E. Meserve, M. Nelkin, R. L. VonBerg.

The nuclear science and engineering 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 in the above fields as well as a nuclear engineering major. 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 is concerned with the practical application of scientific knowledge of nuclear reactions and radiations. In this broad context nuclear engineering treats the production of neutrons, gamma radiation, radioisotopes, and transmutation of elements. The aims of the graduate program at Cornell are to provide the student with a thorough understanding of the laws and principles upon which our understanding of nuclear systems is based, and to develop the skills of applying basic principles to engineering problems. The nuclear engineering program includes class instruction, experimental and theoretical research, and engineering synthesis and design.

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 Laboratory contains: (1) A TRIGA reactor which may be operated at a steady-state power of 100 kw producing a neutron flux of 1 to 5 $\times 10^{12}/\text{cm}^2$ sec. In addition, the reactor may be pulsed to a peak power of approximately 250 megawatts for the study of phenomena of brief duration. The width of the pulse at half maximum is approximately 40 millisec. Eight beam ports and a thermal column allow flexible use of neutrons and radiation. (2) A "zero power reactor" (critical facility) of versatile design for basic studies of reactor physics. (3) Subcritical assemblies for similar studies. (4) A shielded cell for chemo-nuclear work with up to 10,000 curie gamma sources and other radioactive materials. (5) A radio-chemistry laboratory. (6) A 3 MV, 0 to 4 milliampere Cockcroft-Walton accelerator for studies of radiation effects and low energy nuclear levels and reactions has recently been added to the facilities of the laboratory.

PREPARATION FOR GRADUATE STUDY

The degree programs that permit concentration in nuclear science, nuclear engineering, or both are the *College Program* (see pp. 12–14), the Master of Engineering (Nuclear), and the M.S. and Ph.D. programs in the graduate field, Nuclear Science and Engineering.

THE COLLEGE PROGRAM: MAJORS AND MINORS

Specialization in nuclear science and engineering may not be achieved during the four undergraduate years. However, the following courses may be considered, subject to approval by the committee on the *College Program,* as an appropriate preparation for the field.

MAJOR IN NUCLEAR ENGINEERING

Physics 436, Modern Physics
Engineering 8351, Nuclear Measurements Laboratory
Engineering 5760, Nuclear and Reactor Engineering
Engineering 6872, Nuclear Materials
Engineering 8303, Introduction to Nuclear Engineering

MINOR IN NUCLEAR ENGINEERING

Physics 436, Modern Physics
Engineering 8303, Introduction to Nuclear Engineering
Engineering 8351, Nuclear Measurements Laboratory
or
Engineering 6872, Nuclear Materials

MASTER OF ENGINEERING (NUCLEAR)

The professional Master's degree program is intended primarily for students who want a terminal degree, and secondarily for students who want an interim degree before doctoral study in nuclear science or engineering. To be considered an applicant should have:

1. A baccalaureate degree in engineering, applied science, or its equivalent,
2. Physics, three years including atomic and nuclear physics,
3. Mathematics, three years including one year of advanced calculus,
4. Thermodynamics.

Students with minor deficiencies from the above list may make them up after admission to graduate study, but more time will likely be required to complete the graduate program.

For Master of Engineering (Nuclear) the following courses are required:

FALL TERM

EP 8312, Reactor Theory I
EP 8333, Nuclear Reactor Engineering
Engineering
Mathematics or Physics

SPRING TERM

EP 8351, Nuclear Measurements Laboratory
EP 8309, Low Energy Nuclear Physics
Engineering
Engineering Design Project

The courses labeled "engineering" above 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).

In addition to the courses already listed, the following may be of interest to students concerned with nuclear science and engineering:

EP 8334, Nuclear Engineering Seminar
EP 8352, Advanced Nuclear and Reactor Laboratory
Physics 444, Nuclear and High Energy Particle Physics
Physics 645, Nuclear Physics
Chemistry 380, Chemical Bonding and Properties of Organic Molecules
Chemical Engineering 5505, Advanced Heat Transfer
EE 4561–4562, Plasma Physics I and II
Aerospace Engineering 7201–7202, Magnetohydrodynamics I and II
Engineering Mechanics 1163, Applied Elasticity
Mechanical Engineering 3661, Advanced Thermodynamics

M.S. AND PH.D. DEGREES

A candidate for either degree may choose, as his major subject, nuclear science or nuclear engineering. The detailed program of studies is not prescribed as a curriculum. Each student's program is worked out individually with the members of his Special Committee. Areas of research in nuclear science include nuclear chemistry, low energy nuclear physics, theory of neutron interactions with matter, radiochemistry, radiation chemistry, activation analysis, and radiation detection. Areas of research in nuclear engineering include neutral particle transport theory, reactor 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. More complete information on M.S. and Ph.D. programs is available in the *Announcement of the Graduate School.* Admission forms and further information may be obtained from the Field Representative, 116 Nuclear Reactor Laboratory.

THEORETICAL AND APPLIED MECHANICS

Thurston Hall

Mr. J. R. Moynihan, Acting Chairman; Messrs. H. D. Block, J. A. Burns, H. D. Conway, E. T. Cranch, M. D. Greenberg, R. H. Lance, G. S. S. Ludford, J. P. Moran, Y. H. Pao, D. N. Robinson, G. E. Smith.

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 courses in theoretical and applied mechanics and applied mathematics, the undergraduate can elect advanced courses. Such courses 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 the newly initiated *College Program* (see page 12).

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 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 light-weight, thin-walled structures; (2) wave propagation in solids – with research on the dynamic response of plates, structures, and machine elements; (3) structural mechanics including static and dynamic loading, vibrations, and buckling; (4) theory of elasticity and plasticity; (5) theoretical fluid mechanics – with research in 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.

DESCRIPTION OF COURSES

The courses listed in the preceding curricula are described in the sections following. Courses are described under the heading of the school, department, or division in which they are offered. Courses in chemistry, English, mathematics, and physics, and certain courses in economics are offered by the College of Arts and Sciences. They are listed under *Basic Studies.*

Courses offered by the Division of Basic Studies in the College of Engineering have three digit numbers. Courses listed under the intercollege division of Computer Science also have three digit numbers and follow the Basic Studies listings. All other courses offered within the College have four digit numbers, the first digit representing the school or department. Descriptions of courses will be found in the section of this Announcement as follows:

1. Aerospace Engineering
2. Agricultural Engineering
3. Division of Basic Studies
4. Chemical Engineering
5. Civil Engineering
6. Computer Science
7. Electrical Engineering
8. Engineering Physics
9. Environmental Systems Engineering (see Civil Engineering)
10. Industrial Engineering and Operations Research
11. Materials Science and Engineering
12. Mechanical Engineering
13. Nuclear Science and Engineering (see Engineering Physics)
14. Theoretical and Applied Mechanics

For courses in other colleges of the University not described here, to be taken either as required courses or as electives, see the Announcement of the appropriate college.

AEROSPACE ENGINEERING

7101. ADVANCED KINETIC THEORY

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.

7102. GASDYNAMICS

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 on flow fields and the method of characteristics including chemical reactions. Experimental techniques.

7103. DYNAMICS OF RAREFIED GASES

Credit 3 hrs. Spring. Prerequisites, 7101, 7102. Flow regimes according to the Knudsen number. Theories of the shock structure at high Mach numbers. Boundary conditions at a solid wall. Slip-flow conditions. Free-molecule flows. Eigen function expansion of the linearized Boltzmann equation. Full-range and half-range moment methods. The model equation approach and recent developments for handling the transition regime.

7104. ADVANCED TOPICS IN HIGH TEMPERATURE GASDYNAMICS

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

7201. MAGNETOHYDRODYNAMICS I

Credit 3 hrs. Fall. Review of electromagnetic theory. Derivation of plasma conservation equations and of Ohm's law. Important parameters in magnetohydrodynamics and Alfvén waves. The pinch effect and hydromagnetic instabilities. Flow problems in magnetohydrodynamics. Hydromagnetic shock waves.

7202. MAGNETOHYDRODYNAMICS II

Credit 3 hrs. Spring. The three fluid model. Plasma oscillations. Tensor conductivity. The Saha equation, mean free paths, collision times. Diffusion and mobility, discharges. Excess electron temperature, collisionless effects.

7203. ADVANCED TOPICS IN PLASMA-DYNAMICS I

Credit 3 hrs. Fall. Prerequisites, 7201, 7202. Large amplitude disturbances and non-linear wave motion in plasmas. Collision-free shocks, wave mixing, and plasma turbulence. A unified treatment will be developed by means of the Vlasov Equations.

7204. ADVANCED TOPICS IN PLASMA-DYNAMICS II

Credit 3 hrs. Spring. Prerequisites, 7201, 7202. The major topic to be considered is the interaction of radiation with plasmas. The scattering and radiation of electro-magnetic waves, the interaction with electrostatic waves, mode conversion and the effect of non-uniform distributions are among topics to be treated.

7301. FLUID MECHANICS I

Credit 3 hrs. Fall. The continuum and the stress tensor. Vectors and tensors. Hydrostatics. Strain and rate-of-strain tensors. The ideal elastic continuum. Equilibrium and compatibility equations, boundary conditions. Plane stress and strain. The stress function. Elastic energy. Castigliano theorem and St. 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.

7302. FLUID MECHANICS II

Credit 3 hrs. Spring. Laplace's equation. Source, sink, and doublet. Vortices. Biot-Savart theorem, the flow field of a vortex. Spherical and cylindrical harmonics. Methods of singularity distributions. Complex-variable methods. Wing theory. Acoustics. Compressible flows, subsonic and supersonic. Shock waves. Hypersonic flow. Rotational flows. Magnetohydrodynamics. Flow in the boundary layer, Prandtl theory. Heat transfer, separation.

7303. FLUID MECHANICS III

Credit 3 hrs. Fall. Prerequisites, 7301, 7302. Aerodynamics of compressible fluids. Brief review of linear theories. Improvements on linear theory. Role of entropy in supersonic flows. Shock wave interactions. Exact theories: method of characteristics for rotational flows; hodograph transformation; conical flows. Transonic flow theory and similitude. Viscous effects in compressible flows. Other topics of current interest.

7304. THEORY OF VISCOUS FLOWS

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.

7305. HYPERSONIC FLOW THEORY

Credit 3 hrs. Spring. 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.

7801. RESEARCH IN AEROSPACE ENGINEERING

(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

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. ADVANCED SEMINAR IN AEROSPACE ENGINEERING

Credit 2 hrs. Prerequisite, approval of the Director. Special research topics under current investigation by the Bell Laboratories and Bellcomm in the Fall Term. Review of research in the General Electric Laboratories in the Spring Term.

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

Credit 3 hrs. Spring. 1 Lect., 2 Lab. Principles and methods of engineering measurements, fundamentals of measurement, sources of errors, and measurement systems, with emphasis upon survey measurements. Special attention will be given to those measurements required in a variety of agricultural engineering design problems. Techniques for solution of these problems by modern digital computing methods will be introduced.

153. ENGINEERING DRAWING

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.

450. SPECIAL TOPICS IN AGRICULTURAL ENGINEERING

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.

451–452. AGRICULTURAL ENGINEERING PROJECT

Total credit 6 hrs. Fifth year work in the form of projects. Individual work, or in small groups, with staff guidance. Primarily intended to develop initiative and self-reliance, as well as to provide for experience with engineering problems. Problems in the student's area of interest will be assigned after consultations between student and staff.

461. AGRICULTURAL MACHINERY DESIGN

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisite, Engineering 3321 or the equivalent. The principles of design and development of agricultural machines to meet functional requirements. Emphasis is given to computer design solutions, stress analysis, selection of construction materials, and testing procedures involved in machine development.

462. AGRICULTURAL POWER

Credit 3 hrs. Fall. 2 Lect., 1 Lab. and computing periods. Prerequisites, 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.

463. PROCESSING AND HANDLING SYSTEMS FOR AGRICULTURAL MATERIALS

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.

471. SOIL AND WATER ENGINEERING

Credit 3 hrs. Spring. 3 Lect., 1 Lab. every other week. Prerequisites, Course 271, Engineering 2301, and Agronomy 200, or their equivalents. An advanced course in 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; and design and operation of sprinkler systems for irrigation.

481. AGRICULTURAL STRUCTURES

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.

491. LOW-COST ROADS

Credit 3 hrs. Primarily for foreign students. Offered upon sufficient demand, usually in fall term. Prerequisite, consent of instructor. Principally directed study with one $2\frac{1}{2}$-hour class session per week. Study of economic considerations in road system improvement; road improvement planning and programing; road location and geometric design; engineering soil characteristics and classification; design of roadbed thickness; drainage; stabilization methods and materials; dust palliatives; wearing surfaces.

501. SIMILITUDE ENGINEERING

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. Introduction to a variety of applications in engineering. It is preferred that students know how to program in Fortran, although knowledge of CORC is acceptable.

502. INSTRUMENTATION

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Application of instrumentation to physical and biological measurements in agricultural engineering research, including measurement of force, displacement, velocity, acceleration, temperature, humidity, fluid flow, and electrical impedance and potential.

600. SPECIAL TOPICS

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

601. GENERAL SEMINAR

Fall and Spring. Required of all graduate students majoring in the field. Presentation and discussion of research and special developments in agricultural engineering.

602. POWER AND MACHINERY SEMINAR

603. SOILS AND WATER ENGINEERING SEMINAR

604. AGRICULTURAL STRUCTURES SEMINAR

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.

BASIC STUDIES DIVISION

Engineering Problems and Methods

103. ENGINEERING GRAPHICS AND DESIGN

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.

104. INTRODUCTION TO ENGINEERING

Credit 3 hrs. Either term. 1 Lect., 1 Rec., 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.

Mathematics

191. CALCULUS FOR ENGINEERS

Either term. Credit four hours. Prerequisite, three years of high school mathematics, including trigonometry. Fall term: lectures, M W F 9, 11 plus recitation periods to be arranged. Spring term: M W F S 9, 11. Preliminary examinations will be held at 7 p.m. on Oct. 19, Nov. 9, Dec. 7, Jan. 11.

Plane analytic geometry, differential and integral calculus, applications.

192–192H. CALCULUS FOR ENGINEERS

Either term. Credit four hours. Prerequisite, 191. Fall term: M W F S 9, 11. Spring term: lectures, M W F 9, 11 plus recitation periods to be arranged. Preliminary examinations will be held at 7 p.m. on Mar. 1, Mar. 22, Apr. 19, May 17.

Transcendental functions, technique of integration and multiple integrals, vector calculus, analytic geometry in space, partial differentiation, applications.

293–293H. ENGINEERING MATHEMATICS

Either term. Credit four hours. Prerequisite, 192. Fall term: lectures, M W F 8, 12 plus recitation periods to be arranged. Spring term: M W F S 9, 11. Preliminary examinations will be held at 7 p.m. on Oct. 18, Nov. 29, Jan. 10.

Vectors and matrices, first order differential equations, infinite series, complex numbers, applications. Problems for programing and running on the automatic computer will be assigned, and students are expected to have a knowledge of computer programing equivalent to that taught in Engineering 104.

294–294H. ENGINEERING MATHEMATICS

Either term. Credit three hours. Prerequisite, 293. Fall term: M W F 8, 12. Spring term: lectures, M W 8, 12 plus recitation periods to be arranged. Preliminary examinations will be held at 7 p.m. on Mar. 14, Apr. 18, May 16.

Linear differential equations, quadratic forms and eigenvalues, differential vector calculus, applications.

Physics

121–122. INTRODUCTORY ANALYTICAL PHYSICS I AND II

Throughout the year. (Physics 121 is also offered in the spring term, T Th S 9, for those students who have completed but failed the course in the preceding fall term; permission of the instructor is required.) Credit three hours a term. Prerequisite, calculus or co-registration in Mathematics 191–192. Course 121 is prerequisite to 122. Primarily for students of engineering. Lecture, T 9, 11 or 2. Two discussion periods per week and one two and one half hour laboratory period every other week, as assigned. Preliminary examinations will be held at 7:30 p.m. on Oct. 25, Nov. 29, Jan. 10, Mar. 14, Apr. 11, May 16.

The mechanics of particles: kinematics of translation, dynamics, conservation of energy. The properties of the fundamental forces: gravitational, electromagnetic, and nuclear. Conservation of linear momentum, kinetic-molecular theory of gases, properties of solids and liquids, mechanics of rigid bodies, harmonic motion. At the level of *Introductory Analytical Physics,* third edition, by Newhall.

223–224. INTRODUCTORY ANALYTICAL PHYSICS III AND IV

Throughout the year. (Physics 223 is also offered in the spring term, T Th S 11, for those students who have completed but failed the course in the preceding fall term; permission of the instructor is required.) Credit four hours a term. Prerequisites, Physics 122 and co-registration in Mathematics 293–294, or equivalent. Course 223 is prerequisite to 224. Lectures, T Th 9 or 11. Two discussion periods and one two and one half hour laboratory period every week, as assigned. (Not all of these six and one half hours will be used each week; class time per week will average five to five and one half hours.)

A survey of electric and magnetic fields including a review and an extension of the study of static fields and their sources. Fields in simple dielectrics, charges in motion, time-varying fields, induced electromotance, fields in magnetic materials, energy of charge and current distributions, electrical oscillations, electromagnetic waves; reflection, refraction, dispersion, and polarization. Superposition of waves; interference and diffraction. Selected topics from contemporary physics such as relativity, quantum effects, atomic and x-ray spectra, nuclear structure and reactions, solid state physics. The laboratory work includes experiments in electrical measurements, physical electronics, optics, and nuclear physics. At the level of *Physics for Students of Science and Engineering* by Halliday and Resnick, and of *Elementary Modern Physics* by Weidner and Sells.

225–226. INTRODUCTORY ANALYTICAL PHYSICS III AND IV

Throughout the year. Credit four hours a term. Prerequisites, same as for Physics 223–224. Course 225 is prerequisite to 226. Class hours, same as for Physics 223–224.

The main topics are the same (none omitted) as those listed under Physics 223–224, but their treatment is more analytical and somewhat more intensive. At the level of *Electricity and Magnetism* by Kip, *Optics* by Rossi, and *Elementary Modern Physics* by Weidner and Sells.

Chemistry

103–104. INTRODUCTION TO CHEMISTRY

Throughout the year. Credit three hours a term. Chemistry 103 is prerequisite to Chemistry 104. Recommended for students who have not had high school chemistry and for those desiring a more elementary course than Chemistry 107–108. If passed with a grade of C minus, this course serves as a prerequisite for Chemistry 205 or Chemistry 353. Lectures, M F 10 or 11. Combined discussion-laboratory period, T or Th 8–11, W 10–1, M T W Th or F 1:40–4:30.

An introduction to chemistry with emphasis on the important principles and facts of inorganic and organic chemistry.

107–108. GENERAL CHEMISTRY

Throughout the year. Credit three hours fall term and four hours spring term. Prerequisite, high school chemistry; 107 is prerequisite to 108. Recommended for those students who will take further courses in chemistry but do not intend to specialize in chemistry or closely related fields. Enrollment limited to 900. Lectures, T Th 9, 10, or 12. Combined discussion-laboratory period, M W F or S 8–11, M T W Th or F 1:40–4:30. In spring term, one additional recitation hour as arranged. Scheduled preliminary examinations may be held in the evenings.

The important chemical principles and facts are covered, with considerable attention given to the quantitative aspects and to the techniques which are important for further work in chemistry. Second-term laboratory includes a scheme of qualitative analysis.

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 the advanced standing examination given at Cornell on the Tuesday before classes start in the fall. Application for this latter examination should be made to the Department of Chemistry no later than registration day.

115–116. GENERAL CHEMISTRY AND INORGANIC QUALITATIVE ANALYSIS

Throughout the year. Credit four hours a term. Prerequisite, high school chemistry at a grade of 90 or higher; Chemistry 115 is prerequisite to Chemistry 116. Recommended for students who intend to specialize in chemistry or in closely related fields. Students without good mathematical competence are advised not to take this course. Enrollment limited to 150. Fall term: lectures, M W F 12; one three-hour combined discussion-laboratory period, T or Th 10–1, W or F 8–11, or W or F 1:40–4:30. Spring term: Lectures, M W 12; two three-hour combined discussion-laboratory periods, T Th 10–1, W F 8–11, or W F 1:40–4:30.

An intensive, systematic study of the laws and concepts of chemistry, with considerable emphasis on mathematical aspects. Laboratory work will cover both qualitative and quantitative analysis.

276. INTRODUCTION TO PHYSICAL CHEMISTRY

Fall term. Credit three hours, Prerequisites, Chemistry 104 or 108 or 116, Mathematics 192, and Physics 122. For engineering students. M W F 9 or 11. Examinations, Th 7:30 p.m.

A brief survey of physical chemistry.

285–286. INTRODUCTORY PHYSICAL CHEMISTRY

Throughout the year. Credit five hours a term. Prerequisites, Chemistry 108 or 116, Mathematics 192, Physics 123, or consent of instructor. For students in engineering, not open to Arts and Sciences students. Lectures, M W F 9. Laboratory lecture, F 12. Laboratories: fall term, M T or W Th 1:40–4:30, or F 1:40–4:30 and S 10:00–12:30; spring term, M T 1:40–4:30 or W Th 1:40–4:30.

The lectures will give a systematic treatment of the fundamental principles of physical chemistry. The laboratory will deal with the experimental aspects of the subject and also develop the needed skills in quantitative chemical analysis.

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.

Electrical Science

241–242. ELECTRICAL SCIENCE I AND II

Credit 3 hours. Throughout the year. 2 Lect., 1 (2½ hour) Rec.-Comp. Prerequisites, Math 192 and Physics 122 and co-registration in Math 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 are developed for calculating the responses to various excitations of simple electrical systems containing these devices. Indicative of the types of systems considered are: networks of linear resistances and capacitances subjected to steady and sinusoidal excitations; circuits containing nonlinear resistances and vacuum or semiconductor diodes; simple triode 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.

341–342. INTRODUCTORY ELECTRICAL ENGINEERING

Credit 3 hrs. per term. 2 Lect., 1 Rec.-Comp. Prerequisites, Math 192, Physics 122 and at least co-registration in Math 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. (Not available to underclassmen.)

Mechanics

211. MECHANICS OF RIGID AND DEFORMABLE BODIES I

Credit 4 hrs. Fall-Spring. 1 Lect., 2 Rec., 1 (2½-hour) Comp.-Lab. Prerequisites, co-registration in Math. 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 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

Credit 4 hrs. Spring-Summer. 1 Lect., 2 Rec., 1 (2½-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.)

Materials Science

6210. MATERIALS SCIENCE

Credit 3 hrs. Fall-Spring. 2 Lect., 1 Lab., 1 Rec., alternate weeks. First offered 1967. Selected topics in physical chemistry and materials science for engineering students. The states of matter and the relation between molecular structure and physical properties. Equilibria in homogeneous and heterogeneous systems. Electrochemistry. Principles underlying structure, properties, and behavior of materials.

6211. MATERIALS SCIENCE

Credit 3 hrs. Spring. 2 Lect., 1 Rec.-Lab. Prerequisite Chemistry 276 or 285, or Engr. 6210. A survey of Materials Science including basic concepts (bonding of atoms in molecules and crystals, energy bands, ideal and nonideal crystalline and noncrystalline structures, microstructures, equilibrium and kinetic behavior of materials) and their applications in understanding selected properties of solids (such as plastic deformation, creep, fatigue, ferromagnetism, conductivity in metals, semiconductors and superconductors) and in understanding selected areas of processing of materials (such as solidification, sintering, zone refining, heat treating and cold working).

Thermodynamics

231. THERMODYNAMICS

Credit 3 hrs. Fall. 2 Lect., 1 Rec.-Comp. Initial concepts. Classical laws of thermodynamics. Microscopic description of thermodynamics. Thermodynamics properties of substances. Chemical reaction rates and equilibrium in homogeneous gas reactions.

232. FLUID MECHANICS

Credit 3 hrs. Spring. 2 Lect., 1 Rec.-Comp. Behavior of fluids with examples. Differential equations of fluid flow. Flow over bluff bodies, drag and lift. Turbulent flow. Flow of gases. One-dimensional gas dynamic processes. Molecular transport in gases.

Chemical Engineering

5101. MASS AND ENERGY BALANCES

Credit 3 hrs. Fall. 3 Lect., 1 Comp. period. Parallel, Physical Chemistry 285. Engineering problems involving material and energy balances. Flow-sheet systems and balances. Total energy balances for flow systems.

5102. EQUILIBRIA AND STAGED OPERATIONS

Credit 3 hrs. Spring. 3 Lect., 1 Comp. period. Parallel, Physical Chemistry 286. Phase equilibria and phase diagrams. The equilibrium stage, mathematical description of single and multistage operations, analytical and graphical solutions.

CHEMICAL ENGINEERING

5041. NONRESIDENT LECTURES

Fall. 1 Lect. Given by lecturers invited from industry and from certain selected departments of the University for the purpose of assisting students in their transition from college to industrial life.

5101. MASS AND ENERGY BALANCES

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Parallel, Physical Chemistry 285. Engineering problems involving material and energy balances. Flow-sheet systems and balances. Total energy balances for flow systems.

5102. EQUILIBRIA AND STAGED OPERATIONS

Credit 3 hrs. Spring. 2 Lect., 1 Comp. Parallel, Physical Chemistry 286. Phase equilibria and phase diagrams. The equilibrium stage; mathematical description of single and multistage operations; analytical and graphical solutions.

5103, 5104. CHEMICAL ENGINEERING THERMODYNAMICS

Credit 3 hrs. each term. Fall-Spring. 3 Lect. Prerequisites, Chemistry 285, 286. 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.

5105. ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 5104 or equivalent. Primarily for graduate students. Application of the general Thermodynamics method to advanced problems in chemical engineering. Evaluation, estimation, and correlation of properties. Chemical and phase equilibria.

5106. REACTION KINETICS AND REACTOR DESIGN

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 5104. A study of chemical reaction kinetics and principles of reactor design for chemical processes.

5107. ADVANCED REACTION KINETICS

Credit 3 hrs. Fall. 3 Lect. Primarily for graduate students. Effects of heat transfer, diffusion, and non-ideal flow on reactor performance. Optimum design for complex reactions. Analysis of current literature on topics such as partial oxidation, catalytic cracking, hydrogenation, and polymerization.

5108. COLLOIDAL AND SURFACE PHENOMENA

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.

5161. PHASE EQUILIBRIA

Credit 3 hrs. Fall. 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 available composition. Prediction of phase data.

5203. CHEMICAL PROCESSES

Credit 4 hrs. Fall. 4 Lect. An analysis of important chemical processes and industries.

5205. CHEMICAL PROCESS SEMINAR

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

5255. MATERIALS

Credit 4 hrs. each term. 4 Lect. Prerequisites, 5101, 5102, Chem. 285, 286. 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. Non-metallic materials, including refractories and cement, are also discussed.

5256. POLYMERIC MATERIALS

Credit 3 hrs. each term. 3 Lect. A study of the chemical and engineering aspects of polymerization processes, fabricating methods, and the correlation of structure with properties and applications of polymers.

5303. ANALYSIS OF STAGE PROCESSES

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Prerequisites, 5101 and 5102. An analysis of separations involving mass transfer in stage processes. Design variables, binary and multicomponent system calculations, efficiencies, and cost estimation for stage processes are considered.

5304. INTRODUCTION TO RATE PROCESSES

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

5353. UNIT OPERATIONS LABORATORY

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.

5354. PROJECT LABORATORY

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

5505. ADVANCED HEAT TRANSFER

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 5507 or equivalent. Heat transfer under unsteady-state conditions; numerical approximation methods; analogies among heat, mass, and momentum transfer; heat transfer to liquid metals; simultaneous heat and mass transfer, etc. Primarily for graduate students.

5506. MASS TRANSFER

Credit 3 hrs. Spring. 3 Lect. Primarily for graduate students. Molecular and turbulent diffusion in binary and multicomponent systems; film, boundary layers, and penetration-theory models of mass transfer; applications to distillation, gas absorption, liquid-liquid extraction, and other industrial operations.

5507. ADVANCED FLUID DYNAMICS

Credit 3 hrs. Fall. 3 Lect. Primarily for graduate students. Viscous laminar flow of Newtonian and non-Newtonian fluids; flow stability; turbulent flow; perfect fluid theory; boundary layer theory; analogies among heat, mass, and momentum transfer.

[5508. APPLIED MATHEMATICS IN CHEMICAL ENGINEERING]

Credit 4 hrs. Fall. 4 Lect. Prerequisite, 5305, 5104. Series and numerical solutions. Partial differential equations. Fourier Series; Bessel Functions; Laplace transforms. Calculus of finite differences. Applications to heat and mass transfer, reaction kinetics, and catalysis. Not offered in 1966–67.

5605, 5606, 5607, 5608. DESIGN PROJECT

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.

5609. ANALYSIS AND DESIGN OF PROCESS EQUIPMENT

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. Primary emphasis is on operations involving solids and fluid-solid mixtures such as mixing, mechanical separations, size reduction, crystallization and drying.

5621. PROCESS DESIGN AND ECONOMICS

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.

5622. PROCESS AND PLANT DESIGN

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; equivalent interest rate of return and discounted cash flow.

[5631. SEPARATION PROCESSES]

Credit 3 hrs. Fall. Prerequisite, 5305. Problems involving the optimum design of equipment for the physical separation of chemical mixtures. Primarily for graduate students. Not offered in 1966–67.

[5632. PROCESS EVALUATION AND DESIGN]

Credit 4 hrs. Spring. Prerequisite, 5631. Techniques and case studies in evaluating chemical processes. Cost estimation for processes, equipment, and plant. Not offered in 1966–67.

5635. MARKETING OF CHEMICAL PRODUCTS

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.

5636. ECONOMICS OF THE CHEMICAL ENTERPRISE

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 5622. Research economics; feasibility studies; information services; venture analysis; depreciation and amortization; planning.

5641. INVENTIONS, PATENTS, AND TRADE SECRETS

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.

5642. DEVELOPMENT ECONOMICS

Credit 3 hrs. Spring. Prerequisites, 5621, 5622, and 5641. Planning, evaluation, and management of development activities in the process industries, as related to research, processing, new products, markets, and long-range growth.

5717. PROCESS CONTROL

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.

5741. PETROLEUM REFINING

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

5742. PRINCIPLES OF POLYMER SYSTEMS

Credit 3 hrs. Fall. 3 Lect. Credit not allowed for both 5256 and 5742. Chemistry and physics of the formation and characterization of polymers. The engineering applications of polymers as plastics, fibers, rubbers, and coatings.

5743. PROPERTIES OF POLYMERIC MATERIALS

Credit 3 hrs. Spring. 3 Lect. Prerequisite 5256 or 5742. Phenomenological aspects and molecular theories of non-Newtonia flow, viscoelasticity, and ultimate tensile properties. Special topics.

5745. ANALYSIS OF POLYMERIC PROCESSES

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 analyses of raw materials, reactor systems, product preparation, and problems in distribution and marketing.

5746. CASE STUDIES IN THE COMMERCIAL DEVELOPMENT OF CHEMICAL PRODUCTS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, or parallel, 5622. For graduate students. Detailed analysis of specific cases involving the development of new chemical products. Particular emphasis is given to planning activities, research justification, and market forecasting. Profitability calculations and projections are required.

5748. FERMENTATION ENGINEERING

Credit 3 hrs. Spring. 2 Lect., 1 Rec. Prerequisites, or parallel courses, Chemistry 286, 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

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.

5752. POLYMERIC MATERIALS LABORATORY

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

5760. NUCLEAR AND REACTOR ENGINEERING

Credit 2 hrs. Spring. 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.

5851. CHEMICAL MICROSCOPY

Credit 3 hrs. Either term. 1 Lect., 2 Lab. Prerequisites, or parallel courses, Chemistry 285, 286, 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, lens systems and photomicrography.

5859. ADVANCED CHEMICAL MICROSCOPY

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

5900. SEMINAR

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

5909. RESEARCH SEMINAR

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

5952, 5953, 5954. RESEARCH PROJECT

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

5955, 5956. SPECIAL PROJECTS IN CHEMICAL ENGINEERING

Credit variable. Either term. Research or studies on special problems in chemical engineering.

CIVIL ENGINEERING

Civil Engineering Materials

2001. ENGINEERING MATERIALS

Credit 3 hrs. Fall & 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.

2010. ADVANCED PLAIN CONCRETE

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.

2011. STRUCTURE AND PROPERTIES OF MATTER

Credit 3 hrs. Fall. 2 Lect. plus conference. Open to graduate students in engineering or the physical sciences or by consent of instructor. Internal structure of materials ranging from the amorphous to the crystalline state. Correlation of the internal structures of materials with their physical and mechanical properties, primarily on a qualitative basis. Applications to various engineering materials.

2041. CIVIL ENGINEERING MATERIALS PROJECT

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

2042. CIVIL ENGINEERING MATERIALS RESEARCH

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

2044. SPECIAL TOPICS IN MATERIALS

On demand. Hours and credit variable. Fall-spring.

Geodetic and Photogrammetric Engineering and Aerial Photographic Studies

2101. ENGINEERING MEASUREMENTS

Credit 3 hrs. Spring. 2 Rec., 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.

2107. ELEMENTS OF SURVEYING

Credit 2 hrs. Fall-Spring. 1 Rec., 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.

2111. ELEMENTARY GEODESY

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

2112. GEOPHYSICAL GEODESY

Credit 3 hrs. Spring. 3 Rec. 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.

2113. GEODETIC CONTROL SURVEYS

Credit 3 hrs. 2 Rec., 1 Lab. Prerequisite, 2101 or 2111. 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.

2115. ADVANCED ENGINEERING MEASUREMENTS

Credit 3 hrs. Fall. Prerequisites, laboratory work involving physical measurements, Math 294, and permission of the instructor. 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; and related data processing methods.

2119. MAP PROJECTIONS

On demand. Credit 3 hrs. Theory of map projections including conformal, equal-area, azimuthal equidistant, et al. projections; coordinate transformations; plane coordinate systems for surveying.

2121. ELEMENTS OF PHOTOGRAMMETRY

Credit 3 hrs. Fall. Lect., Rec., 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.

2122. ADVANCED PHOTOGRAMMETRY

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Prerequisite, 2121. 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.

2123. ANALYTIC AEROTRIANGULATION

Credit 3 hrs. 3 Rec. Prerequisite, 2121. 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.

2131. LAND SURVEYING

On demand. Credit 3 hrs. 3 Rec. Functions and responsibilities of a land surveyor; deeds and land descriptions; land records and land courts. Study of U.S. public land system, metes and bounds, subdivisions, resurveys, cadastral surveys, riparian rights, mineral land surveys, and other land survey systems. Specifications and registration.

2132. CARTOGRAPHY

On demand. Credit 2 hrs. Study of the needs of map users and methods of production of maps to meet these needs. Cartographic principles, systems, and economics.

2133. ENGINEERING SURVEYS

Credit 3 hrs. Spring. 1 Rec., 2 Labs. Prerequisite, 2101 or equivalent. Circular curves, transition curves, earthwork measurement and calculation, construction surveys and project planning from maps.

[2134. SUMMER SURVEY CAMP
Not offered in 1966–67]

2141. PROJECT. GEODETIC OR PHOTOGRAMMETRIC ENGINEERING

On demand. Open to specially selected seniors or graduate students. Projects in the various fields of geodesy and photogrammetry may be developed by conference between professors and students. Hours and credit variable.

2142. GEODETIC OR PHOTOGRAMMETRIC ENGINEERING RESEARCH

On demand. Prerequisites will depend upon the area of studies to be pursued. Special problems in error analysis, geodesy, and photogrammetry as may be arranged.

2143. SEMINAR IN GEODESY OR PHOTOGRAMMETRY

On demand. Credit 1–6 hrs. Open to specially selected seniors or graduate students. Abstraction and discussion of technical papers and publications in the geodetic or photogrammetric field.

Hydraulics and Hydraulic Engineering

2301. FLUID MECHANICS

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

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Prerequisite, 2301. Free surface 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

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

Credit 2 hrs. Fall-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 4 students.

2315. ADVANCED FLUID MECHANICS I

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

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

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

Credit 3 hrs. Fall. Prerequisite, 2301. Physical analysis and design relative to hydrologic processes. Hydrometerology, runoff, floods, unit-hydrograph procedures, channel and reservoir routing.

2321. FLOW IN POROUS MEDIA

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.

2331. RIVER AND COASTAL HYDRAULICS

Credit 3 hrs. Fall. 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 problem 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.

2332. SEDIMENT TRANSPORT

Credit 3 hrs. Spring. Prerequisite, 2331 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.

2333. FLUVIAL PROCESSES

Spring. Credit 2 hrs. Prerequisite, consent of instructors. Seminar, hours to be arranged, field trips. Course offered jointly with Department of Geological Sciences. On demand. The common problems of fluvial processes, hydraulics, and sediment transport are studied along with the appropriate analytical methods and experimental techniques.

2341. PROJECT

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.

2342. RESEARCH IN HYDRAULICS

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.

2343. HYDRAULICS SEMINAR

Credit 1 hr. Fall-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.

2344. SPECIAL TOPICS IN HYDRAULICS

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

Soil Mechanics and Foundation Engineering

2401. ELEMENTS OF SOIL MECHANICS

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

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

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 2401. The natural environments in which soils are formed; the chemical and physical nature of soils; soil classification; the 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

Credit 3 hrs. Spring. Prerequisite, 2410. The 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

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 2401. The mechanics of the development of earth pressure in relation to soil properties and the imposed deformation conditions. The effects of seepage on the development of earth pressure. Design and stability of bulkheads and cofferdams. Pressures on shafts, tunnels and conduits.

The 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

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 2410. 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.

2430. CASE STUDIES IN SOIL MECHANICS AND FOUNDATION ENGINEERING

Credit 3 hrs. Spring. The study of real engineering problems of various types; the importance of the geological environment in recognizing the nature of field problems; the application of mechanics and soil properties to obtain engineering solutions. The preparation of engineering reports.

2441. DESIGN PROJECT IN SOIL MECHANICS AND FOUNDATION ENGINEERING

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

2442. RESEARCH IN SOIL MECHANICS AND FOUNDATION ENGINEERING

Credit 1–6 hrs. On demand. For students who wish to study one particular area of soil mechanics and foundation engineering in depth. The work may take the form of a laboratory investigation, field study, theoretical analyses or the development of design procedures.

2443. SEMINAR IN SOIL MECHANICS AND FOUNDATION ENGINEERING

Credit 1–2 hrs. On demand. Presentation and discussion of technical papers and current research in the general field of soil mechanics and foundation engineering.

2444. SPECIAL TOPICS IN SOIL MECHANICS AND FOUNDATION ENGINEERING

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 practical nature.

Sanitary Engineering

2501. WATER SUPPLY AND WASTE-WATER ENGINEERING

Credit 3 hrs. 2 Lect. 1 Lect.-Dem. Fall. Prerequisite, 2301. Concurrent registration in 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 disposal systems.

2502. WATER AND WASTE-WATER TREATMENT PROCESSES

Credit 3 hrs. 2 Lect., 1 Lab. Spring. Prerequisites, 2301, 2302. Study of the microbiological, chemical, and physical phenomena underlying the treatment of water and of municipal and industrial waste-water, Application of these principles to the analysis and design of unit treatment processes. Laboratory studies of water quality and of unit treatment processes.

2509. ENVIROMENTAL SANITATION

Open to non-civil engineering students. Credit 3 hrs. Fall. Lect.-Discuss., reports and field trips. 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.

2510. CHEMISTRY OF WATER AND WASTE-WATER

Credit 3 hrs. 2 Lect.-Rec., 1 Lab. Fall. 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

Credit 3 hrs. 2 Lect., 1 Lab. Spring. 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. Bacteriological, biological and limnological parameters of water quality and their measurement.

2513. TREATMENT PROCESSES

Credit 3 hrs. 3 Lect. Fall. 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

Credit 3 hrs. 3 Lect. Spring. 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

Credit 3 hrs. Lect.-Discuss. Fall. Prerequisite, permission of the instructor. Intended primarily for graduate engineering and non-engineering students but open to qualified undergraduates. A comprehensive approach to water resources planning and development. Historical and contemporary perspectives of water resources problems, organization and policies.

2516. PHYSICAL BASIS OF WATER RESOURCE PLANNING

Credit 2 hrs. Lect.-Discuss. Fall. Intended primarily for non-engineering graduate students taking water resources as a minor subject. An introduction to hydrologic systems with topics in climate; surface and ground water flow; flood abatement and water quality control. Offers technical background material useful in subsequent courses in the water resources area.

2517. ENVIRONMENTAL SYSTEMS ANALYSIS I

Credit 3 hrs. 3 Lect. Spring. Prerequisite, permission of the instructor. Intended for graduate students but open to qualified undergraduates. Structuring and solution of mathematical programing models with emphasis on linear programing and its extensions. Introduction to Lagrangian multipliers, dynamic programing, queuing theory and game theory. Application of systems analysis techniques to the solution of complex environmental engineering-economic problems.

2518. ENVIROMENTAL SYSTEMS ANALYSIS II

Credit 3 hrs. 3 Lect. Fall or Spring. Prerequisite, Engineering 9320, 9522 or 9530 or permission of the instructor. Advanced topics in the application of mathematical programing and probability theory to the solution of environmental engineering problems. Special emphasis on water resource systems planning and management. Students will be expected to identify and solve practical problems using systems analysis techniques.

2520. ENVIRONMENTAL HEALTH ENGINEERING

Credit 3 hrs. 3 Lect., Reports. Spring. 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 water quality control, air quality control and solid waste disposal.

2521. SIMULATION OF WATER RESOURCE SYSTEMS

Credit 3 hrs. On demand. Prerequisite, courses in hydrology, statistics and water resource economics. Simulation of hydrologic inputs to water resource systems and the physical and economic response of such systems. Use of simulation as a complement to analytic techniques in the design and operation of water resource systems. Examination of the net-benefit response surfaces by random and uniform grid sampling, method of steepest ascent and other optimizing techniques.

2535. THE LEGAL BASIS OF WATER RESOURCES PLANNING

Credit 3 hrs. Spring or Fall. Prerequisite, permission of the instructor. The course is designed specifically for non-law students interested in the legal aspects of water resources planning, development and management.

2541. DESIGN PROJECT IN WATER RESOURCES ENGINEERING OR IN SANITARY ENGINEERING

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.

2542. SANITARY ENGINEERING RESEARCH

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.

2543. SANITARY ENGINEERING COLLOQUIUM

Credit 1–2 hrs. Fall–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.

2545. WATER RESOURCES PLANNING SEMINAR (Also Economics 638)

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 (Also Economics 640)

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 over-all problem. Taught by engineering and economics faculty.

Transportation Engineering

2601. TRANSPORTATION ENGINEERING

Credit 3 hrs. Fall-Spring. 2 Rec., 1 Lab. Transportation systems, traffic and operation, environmental investigations, transportation planning, highway engineering, other transportation modes, discussions of current issues.

2612. HIGHWAY LABORATORY—BITUMINOUS

Credit 3 hrs. Fall. 2 Lab., 1 Rec. Prerequisite, 2601, or may be taken concurrently with 2601. Physical, rheological, and durability properties of bituminous materials. Principles of the design of bituminous mixtures, including methods of test and the influence of aggregate, binder, test temperature, and rate of load application on the strength and flexibility of paving mixtures. Production of bituminous mixtures and construction practice. Laboratory fully equipped for all phases of applied and research studies.

2613. HIGHWAY LABORATORY — SUBGRADE SOILS

On demand. Credit 3 hrs. 2 Lab., 1 Seminar. Prerequisite, permission of instructor. Soil surveying, sampling, and classification. Correlation of field and laboratory procedures. Tests on soil samples stabilized with bituminous materials, Portland cement and chemicals. Condition surveys on stabilized roads. Evaluation of current practice and development. Laboratory fully equipped for all phases of applied and research studies.

2616. HIGHWAYS AND AIRPORTS

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 2601 or permission of the instructor. Part I: soil index properties and classification systems; subgrade strength evaluation; compaction; drainage and frost action; stabilization; aggregates. Part II: design and construction of base and surface courses for flexible pavements. Part III: design and construction of rigid pavements. Part IV: airport site selection; master plan; terminal facilities; heliports.

2618. LOW-COST ROADS

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.

2621. ANALYSES AND INTERPRETATION OF AERIAL PHOTOGRAPHS

Preregistration required. Credit 3 hrs. Fall-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.) A study of the soil and rock areas of the United States and the patterns present in aerial photographs. Fundamental elements of soil patterns are analyzed to permit determination of soil texture, type of bedrock, and drainage properties. Field training in selected test areas.

2622. ADVANCED INTERPRETATION OF AERIAL PHOTOGRAPHS

Preregistration required. Credit 3 hrs. Fall-Spring. Course includes lectures and team projects in lab. and field. Facilities include material for city-regional planning, soil mapping, conservation, ground and surface water and civil engineering projects.

2626. TRAFFIC ENGINEERING

Credit 3 hrs. Fall-spring. 2 Rec., 1 Lab. Prerequisite, permission of the 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 pattern. Traffic engineering organization. Knowledge of simple programming procedures (CORC) desirable but not mandatory.

2627. TRAFFIC ENGINEERING – OPERATIONS

On demand. Credit 3 hrs. 2 Lab., 1 Seminar. Prerequisite, preceded by or taken concurrently with 2626. Definition of traffic problems, collection of field data, analysis of field data, findings, conclusions, and recommendations. Traffic surveys. Design of traffic control systems.

2628. HIGHWAY GEOMETRIC DESIGN

Credit 3 hrs. Spring. 1 Lect., 2 Lab. Prerequisite, 2601 or permission of the instructor. Route selection; design controls and criteria, including vehicle characteristics and highway capacity; sight distance, and horizontal and vertical control; cross section elements; right-of-way problems and access control; at-grade intersection design, including rotary and channelized intersection; grade separations and interchanges; regional systems of highways.

2631. PHYSICAL ENVIRONMENT EVALUATION

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Intended for graduate students or upperclassmen in engineering and planning. 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 sources in different parts of the world. Evaluation methods include air and ground reconnaissance, interpretation of meteorological, topographic, geological, and soil maps, aerial photography, engineering data, and sub-surface exploration records.

2632. ADVANCED PHYSICAL ENVIRONMENT

On demand. Credit 3 hrs.

2641. TRANSPORTATION ENGINEERING PROJECT

On demand. Credit 1–6 hrs. Projects in the various fields of transportation, advanced aerial photographic studies, traffic engineering, and earth engineering may be developed by conference between professors and students. Projects may involve integrated planning or design, drawing upon several fields of interest, or they may concentrate upon special subjects. Adequate facilities, material, and sources of data are necessary for a satisfactory project.

2642. TRANSPORTATION ENGINEERING RESEARCH

On demand. Hours and credit variable. Students who wish to pursue one particular branch of transportation engineering further than can be done in any of the regular courses may elect work in this field. The work may be in the nature of an investigation of existing methods or systems, theoretical work with a view to simplifying present methods of design or proposing new methods, or experimental investigation of suitable problems.

2643. TRANSPORTATION ENGINEERING SEMINAR

On demand. Credit 1–2 hrs. Number of meetings a week to be arranged. Abstraction and discussion of selected technical papers and publications in the transportation engineering field.

2644. TRANSPORTATION SPECIAL TOPICS

On demand. Credit varies.

See pg. 128 for further offerings.

Structural Engineering

2701. STRUCTURAL ENGINEERING I

Credit 3 hrs. Fall. 2 Lect., 1 2-hour period. Prerequisites, Mech. 212 and conc. reg. in Materials Science I. 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

Credit 3 hrs. Spring. 2 Lect., 1 2-hour period. Prerequisite, 2701, Material Science I, and conc. reg. in Engineering Materials. 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

Credit 3 hrs. Fall. 2 Lect., 1 2-hour period. Prerequisite, 2702, Engineering Materials. 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

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

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 2704; 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

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 post-buckling strength of plates, shear webs, and cylindrical shells. Critical discussion of current design specification.

2712. ADVANCED STRUCTURAL ANALYSIS

Credit 2 or 3 hrs. Fall. 3 Lect. per week. Prerequisite 2703 or equivalent. Brief review of fundamental methods of analyzing hyperstatic structures and extension to complex structural systems. Real, virtual, and complementary work theorems. Elastic arch theory and design considerations. Curved beams, out-of-plane loading, grids, suspension systems, and other special structures. Plastic analysis.

2713. MATRIX STRUCTURAL ANALYSIS

Credit 3 hrs. Spring. 3 Lect. per week. Prerequisite 2712 or equivalent, short course in computer programming, and consent of instructor. The use of matrix algebraic methods of analysis of complex frameworks. Matrix formulation of generalized hyperstatic analysis, including generalized flexibilities of finite structural elements. Idealization techniques. Finite beam theory with applications to members on spring foundations, to secondary arch analysis, and to the analysis of suspension bridges. Use of digital computer (currently CDC 1604) for solution of problems.

2714. STRUCTURAL MODEL ANALYSIS AND EXPERIMENTAL METHODS

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 IN STRUCTURAL ENGINEERING

Credit 3 hrs. Fall. Prerequisite, differential equations and consent of instructor; concurrent registration in FORTRAN instruction. Newmark's method and other numerical integration techniques. Solution of linear systems. Finite difference techniques for stress, stability, and other boundary value problems. Eigenvalue determination. Applications of digital computers in structural engineering analysis and design, including introduction to optimization techniques. Independent projects involving extensive use of digital computer.

2716, 2717. BEHAVIOR AND DESIGN OF CONCRETE STRUCTURES

Credit 3 hrs. a term .Fall-spring. Prerequisite 2703 or equivalent. Analysis, design, and behavior of prestressed concrete and continuous reinforced concrete frameworks. Design of folded plate structures.

2718, 2719. BEHAVIOR AND DESIGN OF METAL STRUCTURES

Credit 3 hrs. a term. Fall-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.

2720. SHELL THEORY AND DESIGN

Credit 3 hrs. Fall. Prerequisite, Math 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 of reinforced concrete roofs and pressure vessels. Stability of certain types of shells.

2721. SPECIAL TOPICS IN MATRIX ANALYSIS

Credit 2 hrs. Spring. 2 Lect. per week. Prerequisite, a prior exposure to matrix methods of structural analysis; 2713 may be taken concurrently. Analysis of tall buildings. Methods of tridiagonalization, transfer matrices. Iterative and direct solutions. Finite element analysis. Non-linear problems. Eigenvalue problems; buckling and dynamic analysis.

2722. DYNAMICS OF STRUCTURES

Credit 3 hrs. Spring. Prerequisite, Math 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.

[2733. STRUCTURAL SYNTHESIS AND PLANNING
Not offered in 1966–67]

2741. DESIGN PROJECT IN STRUCTURAL ENGINEERING

(Meets project requirement for M. E. 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.

2742. RESEARCH IN STRUCTURAL ENGINEERING

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.

2743. STRUCTURAL ENGINEERING SEMINAR

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.

2744. SPECIAL TOPICS IN STRUCTURAL ENGINEERING

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.

Special and Graduate Courses

2801. THESIS

The thesis gives the student an opportunity to work out a special problem or to make an engineering investigation, to record the results of his work, and to obtain academic credit for such work. Registration for 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.

Construction Engineering and Administration

2901. CONSTRUCTION ENGINEERING

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, caisson foundations, etc.; problems and oral reports by students based on current literature.

2902. LAW FOR ENGINEERS

Credit 3 hrs. Fall-spring. 3 Rec. Basic features of laws and practices relating to contracts. torts, agency, property, water rights, business organizations, sales.

insurance, labor, governmental regulation of business, negotiable instruments, 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.

2903. ENGINEERING ECONOMY

Credit 3 hrs. Fall-spring. Principles and techniques for making decisions about the economic aspects of engineering projects: choosing between alternatives; criteria for making decisions; time value of money; economic selection and operation; effect of income taxes; retirement and replacement; economy studies for government activities; introduction to estimating costs of construction.

2904. PUBLIC ADMINISTRATION

On demand. Credit 3 hrs. 3 Rec. Aspects of federal, state, and local government of interest to engineers, planners, constructors, and administrators: general principles of administration; patterns of government; the engineer's role in government; problems posed by our rapidly growing population and urbanization; regional public works projects; city and regional planning; codes; zoning; planning capital improvements; the city manager; managing and operating the engineering and other functions of municipalities.

2906. LEGAL PROBLEMS IN CONSTRUCTION

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 2902. An intensive investigation by the use of case material into the legal principles and practices affecting the work of the civil engineer in construction, particularly unknown site conditions, difficulties in construction, extensions of time, employer-employee relationships, liabilities of engineers and contractors to third parties, acquisitions of rights-of-way; detailed study of contract documents used in construction.

2907. CONSTRUCTION MANAGEMENT

Credit 3 hrs. Planning and operation of construction projects by the civil engineer: coordinated organizations and control of men, materials, and machines; scheduling; estimating; purchasing; selection and training of employees; operation and maintenance of equipment; cost control; accident prevention; and other topics. Special reports required.

2908. ENGINEERING PRACTICE

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.

2941 PROJECT, CONSTRUCTION ENGINEERING AND ADMINISTRATION

Credit 3 hrs. On demand. Prerequisites, 2901, 2902, 2903, or permission. Development of a public or private engineering project selected by the student, involving economic analysis, planning, design, and construction procedures, with special emphasis on the legal, financial, and management aspects.

2942. CONSTRUCTION ENGINEERING AND ADMINISTRATION RESEARCH

On demand. Credit 3 hrs. Prerequisites, 2901, 2902, 2903, or permission. Investigation of special problems relating to the economic, legal, financial, and management aspects of public and private engineering operation of interest to the engineer-administrator, consulting engineer, and constructor.

2943. CONSTRUCTION ENGINEERING AND ADMINISTRATION SEMINAR

On demand. Credit 1–6 hrs. Prerequisites, (or concurrently), 2901, 2902, 2903, or permission. Guided study and discussions by small groups of selected students of topics which involve the legal, financial, and management aspects of civil engineering in public and private work, including discussions of current technical papers and publications.

See pg. 128 for further offerings.

COMPUTER SCIENCE

[201. SURVEY OF COMPUTER SCIENCE]

Spring term. Credit three hours. Introduction to the structure and use of the modern digital computer. This course is intended to be a non-mathematical treatment of the material, and emphasis is on non-numeric computer applications such as information retrieval, language processing, and artificial intelligence. A limited introduction to programming in a problem-oriented language is included. Not offered in 1966–67.

301. INTRODUCTION TO COMPUTER SCIENCE

[In 1966–67 given as Engineering 9381.] Spring term. Credit three hours. Prerequisite, Mathematics 293 or equivalent. Introduction to programming and programming systems. Computer organization and characteristics. Survey of computer applications. Intended for science majors and engineering students, who should have mathematics to a level comparable to Mathematics 293. Students without this background should take CS 201. Students interested primarily in programming should ordinarily take CS 311.

311. DIGITAL COMPUTER PROGRAMMING

Through the year. One or two credit hours. Prerequisite, consent of instructor. The first half of the term is concerned with FORTRAN programming and operating procedures; the second half with assembly language programming. The two sections are independent and a student can register for one credit hour and take either the first or second, or register for two credit hours and take both sections.

321. NUMERICAL CALCULUS

Fall term. Credit four hours. Prerequisite, Mathematics 213 or equivalent. The computational aspects of calculus and related mathematics are discussed in the light of modern computing machines. Topics include numerical differentiation and integration, solution of algebraic and differential equations, interpolation, and simple error analysis of these processes. The student is expected to know CORC, the Cornell computing language.

385. AUTOMATA

Spring term. Credit three hours. Prerequisite, Mathematics 294 or 222 or equivalent. 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. INTRODUCTION TO COMPUTER SCIENCE

[In 1966–67 given as Engineering 9481] Fall term. Credit four hours. Prerequisite, Mathematics 293 or equivalent. An introductory course similar in coverage to 301 but more intensive in treatment. Intended principally for students who are majoring in computer science.

411. PROGRAMMING SYSTEMS AND THEORY I

Fall term. Credit four hours. Prerequisite, 301 or equivalent. Concerned with assembly-level and machine-level programming of large-scale digital computing systems. Will consider principles and techniques involving indirect addressing, index registers, input-output control, program interrupts, storage allocation, magnetic tape and disc auxiliary storage, diagnostic methods and routines. Also, advanced programming systems for executive control. Students will program problems for the Control Data 1604-160A at the Cornell Computing Center.

412. PROGRAMMING SYSTEMS AND THEORY II

Spring term. Credit four hours. Prerequisite, 411 or equivalent. Concerned with theory and techniques of programming languages and programming systems for large-scale digital computer systems. Will consider programming aspects of time-sharing, multiprogramming, real-time, and satellite systems. Also, the structure and form of different types of programming languages including assemblers, interpreters, compilers, and list processors. Basic techniques for scanning, ordering, and translating will be covered. Students will design and implement several simple programming languages during the term.

417. ADVANCED INFORMATION PROCESSING

Fall term. Credit four hours. Prerequisite, 401 or equivalent experience. Provides a theoretical foundation in information processing, with emphasis on the use of computers for the solution of primarily nonnumeric problems. Covered are recent development 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.

421. NUMERICAL ANALYSIS

Fall term. Credit four hours. Prerequisite, Mathematics 222 or 294 or the equivalent and Computer Science 301, or consent of instructor. Covers essentially the same topics as Computer Science 321 but in a more complete fashion and with more emphasis on error analysis and mathematical rigor.

422. NUMERICAL ANALYSIS

Spring term. Credit four hours. Prerequisite, 421 or consent of instructor. Numerical methods in matrix analysis and the solution of partial differential equations.

435. INFORMATION ORGANIZATION AND RETRIEVAL

Spring term. Credit four hours. Prerequisite, 401 or equivalent. 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.

[481. FORMAL LANGUAGES]

Spring term. Credit four hours. Prerequisite, 401, 485–486, 488 or consent of instructor. 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. Not given in 1966–67.

485–486. THEORY OF AUTOMATA I AND II

Throughout the year. Credit four hours. Prerequisite, Computer Science 401, Mathematics 481 or consent of instructor. Automata theory is the study of abstract computing devices; their classification, structure and computational power. Topics include finite state machines, regular expressions, pushdown-automata, linear bounded automata, context free and context sensitive languages, Turing machines and the study of computational complexity.

488. THEORY OF EFFECTIVE COMPUTABILITY

Spring term. Credit four hours. Prerequisite. Computer Science 401, 485, Mathematics 481, or consent of instructor. 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.

490. SPECIAL INVESTIGATIONS IN COMPUTER SCIENCE

Throughout the year. Credit and sessions to be arranged. 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.)

491. COMPUTER SCIENCE GRADUATE SEMINAR

Throughout the year. Credit one hour. For graduate students interested in computer science. A weekly meeting for the discussion and study of important topics in the field.

522. ADVANCED TOPICS IN NUMERICAL ANALYSIS

Spring term. Credit four hours. Prerequisite, 422 and Math. 312, 413 and 331. Current literature dealing with specific areas of numerical analysis will be carefully analyzed.

[585. Seminar in Theory of Computation. Not given in 1966–67.]

DATA PROCESSING SYSTEMS (Engineering 9582)

Fall term. Credit four hours. Prerequisite, Computer Science 301 or BPA 901 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.

DIGITAL SYSTEMS SIMULATION (Engineering 9580)

Fall term. Credit four hours. Prerequisite, Computer Science 301 and a course in probability. 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. Applications of simulation to queuing, storage, traffic, and feedback systems. Applications will include use in the design of facilities, design of operating disciplines, and use in real-time control of an operating system.

SWITCHING SYSTEMS I (Electrical Engineering 4587)

Fall term. Credit three hours. Prerequisite, Electrical Engineering 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 4588)

Spring term. Credit three hours. Prerequisite Electrical Engineering 4587 or equivalent. Synchonous 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

Credit 4 hrs. 3 Lectures, 1 Rec.-Comp., Prerequisites, Electrical Science 242 and Math 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.

4401. DETERMINISTIC SIGNALS IN LINEAR SYSTEMS

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. Prerequisite, 4302. Analysis of linear systems subjected to arbitrary excitations. Fourier, double-sided Laplace and z-transforms by contour integration in the complex plane. Properties of network functions, Positive real functions, Nyquist Criterion. Frequency-domain analysis by transforms; time-domain analysis by the convolution integral; s-plane transformations; singularity functions applied to signal synthesis and the representation of initial conditions. Applications including modulation systems.

4402. RANDOM SIGNALS IN LINEAR SYSTEMS

Credit 4 hrs. Spring. 3 Lect., 1 Rec.-Comp. Prerequisite, 4401. Analysis of linear systems subjected to random excitations. Introduction to probability, random variables, expectations, sequences of random variables. Random processes, statistical and time averages. Input output relations in linear systems. Matched filter systems, linear mean square estimation, the orthogonality principle. Modulation systems and noise.

ELECTROPHYSICS SEQUENCE

4311–4312. ELECTROMAGNETIC FIELDS AND WAVES

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.

4411. QUANTUM THEORY

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. Prerequisite, 4312. Introduction to non-relativistic quantum theory; experimental basis for wave-particle duality; structure of the theory in terms of wave functions; operators, and matrix elements; solution of Schroedinger's equation for one- and three-dimensional potentials; angular momentum; perturbation theory; spin; interaction of atoms with static and radiation fields; central field model of atomic structure and the Pauli exclusion principle, quantum statistics; structure of crystalline solids.

4412. SOLID-STATE PHYSICS

Credit 4 hrs. Spring. 3 Lect., 1 Rec.-Comp. Prerequisite, 4411. Introduction to solid-state physics based on quantum theory; binding in ionic and covalent crystals; free electron theory of metals with application to electrical conductivity and electron emission; band theory of solids; semiconductor theory including application to p-n junction devices; dielectric properties of solids; magnetism; super-conductivity.

LABORATORY SEQUENCES

4321. ELECTRICAL LABORATORY I

Credit 4 hrs. Fall. 1 Lect., 2 Lab. Basic instrumentation and electrical measurements involving circuits and fields of passive electrical elements; elementary mechanical and electrical resonant circuits; and an experimental introduction to physical electronics.

4322. ELECTRICAL LABORATORY II

Credit 4 hrs. Spring. 1 Lect., 2 Lab. Basic experiments concerning parallel wire transmission lines; energy conversion methods; amplifiers and oscillators; high vacuum techniques; and fundamental properties of plasmas.

4421. ELECTRICAL LABORATORY III

Credit 4 hrs. Fall. 1 Lect., 2 Lab. Advanced experiments concerning wave composition and shaping; analog computers: modulation; interaction of rotating and traveling electromagnetic waves with solid and fluid conductors; high frequency properties of dielectrics; high frequency properties of plasmas; and reflection, refraction, and scattering of radio waves.

4422. ELECTRICAL LABORATORY IV

Credit 4 hrs. Spring. 1 Lect., 2 Lab. Advanced experiments concerning filters; feedback amplifiers; multivibrators; parametric amplification, noise; drift, diffusion and recombination of carriers in semiconductors; internal fields and spontaneous polarization; magnetic resonance; and physical properties of C.W. optical gas masers.

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. For the courses that follow, the digits in the four-digit course number have significance as follows (see page 49).

SEMICONDUCTOR AND QUANTUM ELECTRONICS

EE 4531. QUANTUM ELECTRONICS I

Credit 4 hrs. Fall. 3 Lect., 1 Rec.-Comp. Prerequisites, EE 4311, EE 4412, and Physics 443 or EE 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.

EE 4532. QUANTUM ELECTRONICS II

Credit 4 hrs. Spring. 3 Lect., 1 Rec.-Comp. Prerequisite, Quantum Electronics I 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 realted problems; nonliner optical phenomena and multiple-photon processes; interaction of intense light waves with molecular vibrations and elastic waves; theory and properties of molecular and semiconductor masers; characteristics of optical resonators.

4533. SEMICONDUCTOR ELECTRONICS I

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisite, 4412. The physical theory of p-n junction devices; device fabrication; properties of semiconductor devices such as diodes and rectifiers, tunnel diodes, solar batteries, transistors, four-layer devices (diodes, controlled rectifiers and switches), etc.; device equivalent-circuit representations; bias-stabilized transistor amplifiers.

4534. SEMICONDUCTOR ELECTRONICS II

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Prerequisite, 4533. 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.; integrated circuits; parametric amplification.

4535. INFRARED AND OPTICAL PROPERTIES OF SOLIDS

Credit 4 hrs. Fall. 3 Lect. 1 Rec. Prerequisite, 4412 or Physics 454 or consent of instructor. Macroscopic dielectric properties of solids: complex permittivity and permeability, Fresnel equations, reflection and refraction by lossless and lossy media, anisotropic dielectric constant tensor, rotation and deflection of radiation by electro-optic crystals; Microscopic formulation of dielectric properties; electronic, atomic and orientation polarization, dielectric dispersion via resonance or relaxation, local internal field and spontaneous ordering, introductory lattice dynamics, lattice frequency spectrum, application of group theory to derivation of selection rules for infrared and Raman active normal modes. Extended-frequency analysis of vibrational spectra with applications to ferroelectrics.

POWER SYSTEMS AND MACHINERY

4441. CONTEMPORARY ELECTRICAL MACHINERY I

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.

4442. CONTEMPORARY ELECTRICAL MACHINERY II

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.

4443. POWER SYSTEM EQUIPMENT

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.

4444. HIGH VOLTAGE PHENOMENA

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.

4543. UNIFIED THEORY OF ELECTROMECHANICAL SYSTEMS

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Prerequisites, 4441, 4442, or consent of instructor. Electric machines studied as networks of coupled circuits with periodically varying parameters; forces and torques in electromechanical systems; electromagnetic and electrostatic transducers; Kron's basic machine with its practical derivatives; the synchronous, induction and commutator machines in the transient and steady state; frequency response methods applied to machines.

4545. ELECTRIC ENERGY SYSTEMS I

Credit 4 hrs. Fall. 3 Lect.-Rec., 1 Lab.-Comp. Prerequisite, 4422 or 4302 and consent of instructor. The physical and engineering principles that underlie the steady-state operation, control and development of modern electric power systems, with emphasis on the characteristics and operational analysis of major power-system parameters and components. Topics include electromechanical energy converters, direct thermal energy converters, magneto-hydrodynamics, fuel cells, conventional and extra-high-voltage transmission lines and cables, high-voltage-direct-current transmission, half-wave lines, cryogenic lines; power-system network theory; power-angle equations and the circle diagram; the two-machine system; load-flow analysis of complex systems. Several computing periods will involve power laboratory experiments. Load-flow studies will be performed on the digital computer.

4546. ELECTRIC ENERGY SYSTEMS II

Credit 4 hrs. Spring. 3 Lect. Rec., 1 Lab.-Comp., Prerequisite, 4545. A continuation of modern power-system analysis with emphasis on abnormal and transient conditions of operation. Topics include unbalanced three-phase systems; theory of symmetrical components; fault analysis of complex systems; introduction of the principles of protective relaying; constant-flux-linkage theorem; synchronizing and damping torque for salient pole and solid rotor machines; basic assumptions for transient stability studies; the Swing Equation; transient stability of complex networks; control of system frequency; switching and lightning surges; theory of the electric arc; a-c circuit interruption; harmonic conditions in three-phase networks; the phenomena of ferroresonance. Several computing periods will be used for demonstrations and laboratory experiments. Fault studies and transient stability studies will be performed on the digital computer.

MICROWAVE AND PHYSICAL ELECTRONICS

4452. PHYSICAL ELECTRONICS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4312. Fundamental theory of electron devices; particle dynamics; generation and formation of electron beams; electrostatic and magnetic lenses; space charge phenomena; limitations at high frequencies; noise; interaction of electron streams and electromagnetic waves in localized and distributed regions; the electron ballistic and space charge wave approaches; application to planar vacuum tubes and microwave tubes.

4512. FIELDS, WAVES AND ELECTRONS

Credit 4 hrs. Spring. 3 Lect., 1 Rec. Prerequisites, 4412, 4511. Electromagnetic fields and waves in metal and dielectric wave guides and cavities; plasmas and electron-beam generation; fields and waves in stationary and moving plasmas, coupling of modes of wave propagation; sources of electronic noise.

4551. ADVANCED PHYSICAL ELECTRONICS

Credit 4 hrs. Fall. 3 Lect. 1 Rec. Prerequisite, 4512. A study of the physical theories underlying devices based on the controlled flow of electric charges in vacuum, gases, and solids. Review of the fundamental principles: energy exchange, effects of magnetic fields, space charge, collisions, velocity spread, etc. Charge flow across metal-vacuum boundaries: thermionic, secondary, photoelectric, and high field emission. Charge flow across semiconductor contacts: diodes, transistors, field effect transistors. Tunneling phenomena: thin films, tunnel diode analysis. Thermionic devices: high power electron optics, classical electron devices. Gaseous electron devices.

4552. MICROWAVE ELECTRONICS

Credit 4 hrs. Spring. 3 Lect. 1 Rec. Prerequisite, 4512. Fundamental theories of high vacuum, gaseous, and solid state microwave devices. Review of fundamental relations: wave equation, equations of motion, power flow, Liouville equation, etc. Field theory for electron and gaseous electron devices: study of klystrons, traveling wave tubes, wave propagation in stationary plasmas, Faraday effect, etc. Coupled mode theories and ballistic theories. Generalized study of electron stream networks with application to microwave tubes and to solid state microwave dielectric diodes and triodes. Properties of solid state devices at microwave frequency: microwave transistors, parametric diodes, tunnel diodes, injection lasers, gas lasers. Contemporary topics include: Gunn oscillator, Read diode oscillators, approaches to high power solid-state microwave generation, etc.

4553. MICROWAVE ELECTRONICS LABORATORY

Credit 1–3 hrs. 2 Labs. for 3 hrs. credit. Fall. Prerequisites, 4461, 4452. Selected experiments in the area of measurement of active and passive microwave devices including klystrons, traveling-wave tubes, magnetrons, cavities, and periodic structures; term experiment; stress laid upon independent work by the student.

4554. VACUUM AND PHYSICAL ELECTRONICS LABORATORY

Credit 1–3 hrs. 2 Labs. per week for 3 hour credit. Spring. Prerequisites, 4312, 4422. Experiments in the fields of vacuum, gaseous, and solid-state electronics; selected experiments involving high-vacuum measurements, r-f mass spectroscopy, gas plasma measurements, evaporation measurements; also selected experiments involving such techniques as film evaporation, ceramic-metal sealing; production of ultra-high vacuum; term experiment.

4653. ADVANCED MICROWAVE THEORY I

Credit 4 hrs. Fall. 3 Lect. 1 Rec. Prerequisite, 4512. Intended primarily for graduate students. Microwave circuit theory with emphasis on mathematical techniques. Use of perturbational and variational techniques. Green's functions and scattering matrices for solution of microwave circuit problems. Normal modes in uniform waveguides and cavities; excitation of waveguides; obstacles in waveguides and microwave junctions; quasi-stationary approximations; equivalent circuits.

4654. ADVANCED MICROWAVE THEORY II

Credit 4 hrs. Spring. 3 Lect. 1 Rec. Prerequisite, 4653. Intended primarily for graduate students. Microwave circuit theory with emphasis on mathematical techniques. Inhomogeneous media; ferrites and non-reciprocal networks; microwave filters; periodic circuits; surface waveguide; radiation systems.

WAVE PROPAGATION AND PLASMA PHYSICS

4461. ELECTROMAGNETIC THEORY

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4311. Foundation of electromagnetic theory; vector analysis and introductory potential theory; electrostatic fields in vacuum and dielectrics; magnetic fields and magnetic materials; Maxwell's equations; electromagnetic waves in space, waveguides and cavities; excitation of waveguides; boundary value problems; radiation and scattering of waves. Emphasis will be on mathematical technique.

4462. WAVE PROPAGATION IN THE ATMOSPHERE I

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 4311, 4312. An elementary treatment of wave phenomena in the lower and upper atmosphere of the earth, including radio waves, plasma waves, acoustic waves, and gravity waves.

4467. RADIO ENGINEERING

Credit 3 hrs. Fall. 2 Lect., 1 Comp. Prerequisites, 4311, 4302. A study of communication circuits with distributed constants and the production and propagation of electromagnetic radiation; transmission line theory and applications; impedance matching; ultra-high-frequency generation and transmission; electromagnetic theory; propagation phenomena; antenna characteristics and radiation.

4511. ELECTRODYNAMICS

Credit 4 hrs. Fall. 3 Lect. 1 Rec. Prerequisites, 4312, 4402. Foundations of electromagnetic theory; vector analysis, introductory potential theory, static electric and magnetic fields; boundary value problems; fields in dielectric and magnetic media; electromagnetic stresses, forces, and torques; quasi-stationary fields, eddy currents; transformation to moving reference frames; interaction of fields with rigid and fluid conductors in motion, electromechanical energy conversion; traveling waves in various media, including plasmas; reflection, refraction, and guiding of waves; wave-guides and cavities; radiation and antennas.

4560. RADIO AND COMMUNICATION LABORATORY

Credit 3 hrs. Spring normally, but either term if demand is sufficient. 1 Rec., 1 Lab. Prerequisites, 4467, 4422. Choice of three to five different experiments from the field of electronic circuits, networks, transmission lines; waveguides and antennas. Experiments selected to meet individual needs.

4561. PLASMA PHYSICS I

Credit 3 hrs. Fall. 3 Lect. Prerequisites, 4311, 4312. Available to fourth year students with permission of instructor. Motion of charged particles in fields; adiabatic invariants; collisions; coulomb scattering and bremsstrahlung; Langevin equation; transport coefficients; ambipolar diffusion; elementary discharge theory; plasma oscillations and waves; hydromagnetic equations; diffusion of magnetic lines; plasma confinement and mascroscopic instabilities; test particle in a plasma. Elements of solid-state plasma.

4562. PLASMA PHYSICS II

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4561 or permission of instructor. MHD equations; low-conductivity channel flow; Alfven waves; Friedrich's diagrams; shock waves; magneto-active cold plasma theory; CMA diagrams; quasi-longitudinal and quasi-transverse approximation; whistlers and radio waves; bounded plasma; cyclotron radiation; applications to laboratory and natural phenomena.

4565–4566. RADIOPHYSICS OF THE ATMOSPHERE I AND II

Credit 3 hrs. each term. Fall and Spring. Prerequisites, 4461 or equivalent, 4462 or equivalent. The structure of the radio refractive index in the lower atmosphere and in the ionosphere; advanced treatment of special topics in radio wave propagation in the atmosphere: line-of-sight, ground-wave, wave-guide mode, smooth-earth diffraction, ionospheric reflection, whistler mode, weak scattering by fine-scale structure, backscattering by thermal fluctuations in electron density, and others as interest warrants; interpretation of radio data in regard to atmospheric physics.

4567. ANTENNAS AND RADIATION I

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4311. Linear radiators: formulation of the electromagnetic field in terms of vector and scalar potentials; radiation from an infinitesimal current element; radiation from short dipoles; small loops; resonant wire antennas; long wire antennas; theory of linear arrays; impedence properties of wire antennas, antennas with parasitic elements. Aperture radiators: uniqueness theorem for vector fields; equivalence and induction principle; radiation from open-ended waveguides; horn antennas; reflector antennas; Babinet's principle; slot antennas.

4568. ANTENNAS AND RADIATION II

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4567 or equivalent. Huygens' Principle for electromagnetic fields; application to problems of diffraction and aperture radiators; surface wave antennas; radiation in media other than free space; antenna thermodynamics.

4661. KINETIC EQUATIONS

Credit 3 hrs. Fall. 3 Lect. Prerequisites, 4561, 4562, or permission of instructor. Critical development of the Liouville equation; concept of the ensemble and N-particle distribution function; formulation of the Boltzmann, Vlasov, Fokker-Planck and B-G-K equation from the BBKGY scheme; the correlation function; approach to equilibrium; coarse graining; ergodic and H-theorems; equilibrium ensembles; the transition from microscopic to macroscopic descriptions; two particle and radial distributions; Percus-Yevic theory; Density Matrix.

4662. KINETIC THEORY OF PLASMA

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 4561, 4562, or permission of instructor. Boltzmann equation; Lorentz model, transport coefficients for weakly ionized gases; moments of Boltzmann's equation; MHD equations. Chew-Goldberger-Low theory; relativistic and quantum mechanical modifications of Vlatsov equation; waves in hot plasmas; Landau damping, velocity-space instabilities, quasi-linear theory, fluctuations, cyclotron and Cerenkov radiation from plasma; coulomb scattering and Fokker-Planck equation.

ELECTRICAL SYSTEMS

4501. SYSTEMS WITH RANDOM SIGNALS

Credit 4 hrs. Fall. 3 Lect. 1 Rec. Prerequisite, 4402. Modulation theory; basic principles of AM and FM; introduction to random signals; heuristic development of random variables and processes; statistical and time averages; analysis of linear systems with random excitations; noise in physical systems; optimization techniques; filtering; prediction; compensation; matched systems.

4502. STATISTICAL ASPECTS OF SYSTEM ANALYSIS

Credit 4 hrs. Spring. 3 Lect. 1 Rec. Prerequisite, 4501. Development of statistical concepts and their application to system problems. Sampling; estimation of parameters; regression; hypothesis testing. Basic elements of information theory with application to various transmission systems.

4503. THEORY OF LINEAR PHYSICAL SYSTEMS

Credit 4 hrs. Fall. 3 Lect. Prerequisite, 4402 or 4404, or consent of instructor. The state space approach to linear system theory. The concept of state; basic properties of the state and the state equation; state vectors and equations of linear differential systems; modes in linear systems; time varying linear systems; the adjoint system; stability; generalized functions and the Fourier Transform; properties of system functions; discrete-time linear systems; controllability, and observability.

4504. THEORY OF NONLINEAR SYSTEMS I

Credit 4 hrs. Spring. 3 Lect. Prerequisite, 4503. Analysis of first and second order nonlinear systems with applications. Phase plane analysis of autonomous systems; singular points, limit cycles, and the theory of equilibrium; theories of Bendixson, Lienard, and Poincare; relaxation behavior in the phase plane; perturbation theory, existence, convergence, and periodicity of perturbation series; method of Krylov and Bogoliubov. Forced nonlinear systems, harmonics, subharmonics, jump phenomena, and frequency entrainment; periodic systems, Floquet theory, Mathieu-Hill theory, applications to the stability of nonlinear systems and to parametrically-excited systems.

4505–4506. OPTIMIZATION AND APPROXIMATION TECHNIQUES I AND II

Credit 4 hrs. Fall and Spring. 3 Lect. Prerequisite, 4402 and current registration in 4503 and 4504 or consent of instructor. Optimization and approximation techniques used in the synthesis of systems and signals, with applications in control and communication. The approximation problem; linear vector space interpretation, L_p and weighted norms, convex functions, existence and uniqueness of solutions. Least-squares approximations and orthogonal functions; completeness, orthogonalization procedures, measurement of expansion coefficients, complementary filters. Chebyshev and L_1 approximations; Chebyshev sets, uniqueness. Nonlinear approximations; choice of basic function parameters, exponential approximation, optimum pole positions. Computational methods for parameter optimization and approximation problems; gradient algorithms, first and second variations, Lagrange multipliers for equality and inequality constraints, geometric interpretation, vector space projections, convergence. Formulation of deterministic optimization problems in function spaces; equality and inequality constraints, penalty functions. Introduction to the calculus of variations, dynamic programming, and Pontriagin's maximum principle; necessary and sufficient conditions for optimality, boundary conditions. Solution of two-point boundary-value problems by successive approximations; convergence, convexity constraints. Duality and statistical optimization problems. Synthesis of optimal filters and feedback controllers; complexity and stability constraints. Selected topics; sequential optimization, discrete optimization, and min-max problems.

4571. NETWORK THEORY

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4402 or consent of instructor. Fundamental notions of networks and systems through an axiomatic approach to n-ports. The concepts of linearity, causality, stability, activity, duality, and time-invariance: definitions and basic theorems. Rigorous development of linear graph theory and elements of matrix theory. Detailed treatment of how linear n-ports are characterized mathematically: immittance description and properties, state-variable description and properties, scattering description and properties. An introduction to the problem of finding network functions or structures to approximately meet desired behavior in the time- and frequency-domains.

4572. NETWORK SYNTHESIS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4571 or 4503 or equivalent. Logical and systematic approaches for obtaining suitable functions and/or networks from given overall performance specifications. The approximation problem is introduced and then developed from a mathematically abstract point of view: hierarchy of functions, function spaces, fundamental theorems for the existence and uniqueness of solutions. Weighted-least-square approximation: Hilbert Spaces, orthonormalization and completeness of basis. Minimax approximation: theorems of Chebyshev and de la Vallée Poussin, Chebyshev sets. Formal network realizability considerations: classical lossless, immittance and scattering structures. Parametric representation and sensitivity functions. Variational techniques for finding optimal network element values directly from signal-processing requirements in either the frequency or time domain.

4573. RANDOM PROCESSES IN ELECTRICAL SYSTEMS I

Credit 4 hrs. Fall. 3 Lect. Prerequisite, 4402 or 4404 or equivalent. Inadequacy of a deterministic formulation of communication and control problems. Combinatorics and discrete probability. Elements of set theory, and non-denumerable sample spaces. Random variables and their transformations. Moments and correlations. The properties of the normal distribution. The weak and strong laws of large numbers. Engineering importance of exponential convergence. The characteristic functions and the central limit theorem. Problems illustrating use of the developed theory in systems analysis and design.

4574. RANDOM PROCESSES IN ELECTRICAL SYSTEMS II

Credit 4 hrs. Spring. 3 Lect. Prerequisite, 4573 or Math 571. Dependence of random variables: Markov chains and their ergodic properties. Generalization of random sequences to processes. The linear theory of stationary random processes. Relation of time to statistical averages. Spectral Analysis in Hilbert space and its application to random process representation and linear filtering. Normal, poisson, and related processes. Characterization of Markov processes. Non-linear transformations. The course material is treated from the point of view of its applicability to communication and control.

4581–4582. FEEDBACK CONTROL SYSTEMS

Credit 4 hrs. Fall and Spring. Prerequisite, 4402 or consent of instructor. Principles of feedback control systems with emphasis on methods of analysis and synthesis to meet prescribed performance criteria; electronic, electromechanical and electrohydraulic components; root locus, and Bode techniques; cascade and feedback compensation of control systems; complex control systems; sampled data feedback control systems. Laboratory exercises in the form of projects in components, transient and frequency response measurements on complete systems, analog simulation of control systems, and compensating techniques are integrated with the lecture material. Analytical and numerical methods for the investigation and solution of Non-linear Control Systems; applications of Z-transforms to Sampled Data Control Systems; the phase plane; common physical nonlinearities encountered in Control Systems; optimization of relay and Sampled Data Control Systems; dual mode systems; nonlinear compensation techniques; self adaptive control systems. Laboratory work consists of projects of the student's choice. Topic include on-off control systems, non-linear compensation techniques, control system design using analog simulation and control system optimization techniques.

4583. ANALOG COMPUTATION

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisites, 4302 and concurrent registration in 4401, or consent of instructor. Concepts and principles of analog computation; scaling and programming linear, non-linear, and time-varying differential equations; direct simulation of electrical and mechanical systems; analog programming using digital logic. Laboratory work involves solution of problems on a general-purpose analog computer and by arrangement can be devoted in part to special projects to suit the interests and needs of the student.

4587. SWITCHING SYSTEMS I

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Prerequisite, 4322. 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.

4588. SWITCHING SYSTEMS II

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 4587 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.

4589. AUTOMATA (COMPUTER SCIENCE 900)

Credit 3 hrs. Spring. 3 Rec. Prerequisite, Math. 293–294 or Math. 221–222, or equivalent. Both the engineering and mathematical aspects of automata will be introduced. Examples of mathematical topics: Finite-state machines, neural nets, input-output machines. Turing machines, computability. Examples of engineering topics: Machines that learn, adaptive systems, pattern recognition, self-reproducing and self-repairing machines, system reliability, threshold logic systems, biological models, heuristic programming, industrial and technological applications, progress in devices, automatic language translation, cybernetics and robots.

4670. ADVANCED TOPICS IN SYSTEM THEORY

Credit 3 hrs. Term dependent upon demand. A course centered about some broad but particular problems of current interest. Topics vary from semester to semester. One of the major aims of the course is to develop the ability of the student to select needed information from available sources.

4671. THEORY OF NONLINEAR SYSTEMS II

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 4504. Non-autonomous 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.

4673. PROCESSING OF SIGNALS IN NOISE

Credit 4 hrs. Fall. 3 Lect. Prerequisite, 4574. The generation and processing of signals in communication systems. Characterization of time-varying deterministic systems, generalized modulation. Characterization of time-varying non-deterministic systems; random channels, multipath distortion, Doppler shift, signal detection and processing; linear and nonlinear smoothing and prediction, signal-to-noise ratios in simple detectors, matched filters, radar detection and ambiguity functions. Comparison of communication systems in the presence of noise.

4674. TRANSMISSION OF INFORMATION

Credit 4 hrs. Spring. 3 Lect. Prerequisite, 4402 and 4573 or Math 571. 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. Time-discrete continuous channels. Coding and decoding for the band-limited Gaussian channel. Application of information theory to the analysis and design of communication systems.

4680. ADVANCED EXPERIMENTAL CONTROL SYSTEMS

Credit 4 hrs. Either term. 2 Lab. Prerequisite, 4582 or consent of instructor. Limited to graduate students except by special permission. Programs on selected topics in experimental concepts, techniques, and design. Many different experiments are available including: components and systems in the Control System Laboratory; linear and nonlinear system simulation (including compensation) with the analog computer in Phillips Hall and/or the digital computer in the Cornell Computing Center; system optimization (experiment design); discrete control systems; and investigation of methods of adaptation in control systems. During a term the student is expected to perform three to six experiments, selected to meet his individual needs. Emphasis is placed on independent work.

4681. RANDOM PROCESSES IN CONTROL SYSTEMS

Credit 4 hrs. Fall. 3 Lect. Prerequisite, 4574 and 4584. 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.

4682. SEMINAR IN CONTROL SYSTEMS

Credit 2 hrs. Fall or Spring. Prerequisites, 4582, 4681. Open to graduate students who are doing research in the area of control system engineering. Presentation and discussion of current research and publications in control systems and switching systems.

GENERAL

4491. ILLUMINATING ENGINEERING I

Credit 3 hrs. Fall. 3 Rec. Prerequisite, Physics 224. Basic concepts, units and relations in current illuminating engineering. Light sources and computation of light distribution followed by seminar pursuit of current literature on researches and application. Emphasis will be given human reactions to light including color vision, visual comfort, and perception of visual tasks.

4492. ILLUMINATING ENGINEERING II

Credit 3 hrs. Spring. 2 Rec., 1 Lab.-Comp. Prerequisite, 4491. Computation of light-flux distribution and study of difficult lighting problems; emphasis on specialized rather than general lighting problems.

4590. SPECIAL TOPICS IN ELECTRICAL ENGINEERING

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

4591 AND 4592. PROJECT

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

Credit 4 hrs. Fall. 2 Lect., 1 Lab. Laboratory assignments to meet individual needs. Prerequisites, 4401, 4403, or permission of the instructor. Vibrations in strings, bars, membranes, and plates; plane and spherical acoustic waves; transmission, reflection, absorption, resonators and filters; loudspeakers and microphones; speech, hearing, and noise; architectural acoustics; ultrasonic and sonar transducers; underwater acoustics.

4595. ELECTRICAL ENGINEERING DESIGN

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

COURSES FOR OTHER ENGINEERING CURRICULA

4950. ELECTRICAL ENGINEERING

Credit 4 hrs. Spring. 3 Lect., 1 Comp. Prerequisite, 241. Introductory concepts; nonmetallic conduction; electric circuit laws and D-C circuits; magnetics; electromagnetic induction; energy storage elements; alternating currents; analysis of sinusoidally excited circuits; transformers; amplifying devices; linear analysis of electronic circuits; electronic instrumentation; feedback and control; control of discontinuous current flow; D-C machines; A-C machines.

341–342. INTRODUCTORY ELECTRICAL ENGINEERING

Credit 3 hrs. per term. 2 Lect., 1 Rec.-Comp. Prerequisites, Math 192, Physics 122 and at least co-registration in Math 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.

ENGINEERING PHYSICS

8051 and 8052. PROJECT

Terms 9 and 10. 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 over-all planning, in the carrying out of a special problem related to the student's field of interest. The choice of a problem is to be made by the student in consultation with members of the staff.

8090. INFORMAL STUDY IN ENGINEERING PHYSICS

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.

8121–8122. CLASSICAL THERMODYNAMICS

Credit 3 hrs. Throughout the year. 3 Rec. Primarily for majors in engineering physics. Introduction to classical thermodynamics, kinetic theory of gases, and statistical mechanics. Application to physical and engineering problems.

8133–8134. PHYSICAL MECHANICS

Credit 3 hrs. each term. Throughout the year. 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. Mechanics of continua, equilibrium, propagation of sound waves. Elasticity, torsion, shear, bending stresses.

8252. SELECTED TOPICS IN PHYSICS OF ENGINEERING MATERIALS

Credit 1 hr. Fall term. 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

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 ENGINEERING

Credit 3 hrs. Fall. A lecture course for third and fourth year students. Objectives include relating the experience of students in other fields to nuclear engineering and introducing this subject to students who may wish to specialize in it. Topics include: review of nuclear physics, nuclear fission, nuclear reactor theory, radiation shielding, materials of construction of nuclear reactors, nuclear reactor core design, instrumentation and control of nuclear reactors, the separation of stable isotopes, chemical separation and processing of nuclear materials, and thermo-nuclear power. At the level of *Introduction to Nuclear Engineering* by R. L. Murray, Second Edition, Prentice Hall (1961).

8309. LOW ENERGY NUCLEAR PHYSICS

Credit 3 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.

8312. NUCLEAR REACTOR THEORY

Credit 3 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 these processes. Neutron transport theory is introduced at the level of *Nuclear Reactor Theory* by Lamarsh.

8313. REACTOR THEORY II

Credit 3 hrs. 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, non-linear kinetics, perturbation theory, temperature coefficients, control rod theory, hydrogenous reactors, neutron transport and heterogeneous reactor theory. At the level of *The Physical Theory of Neutron Chain Reactors* by Weinberg and Wigner.

8314. NEUTRON TRANSPORT THEORY

Credit 3 hrs. 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.

8333. NUCLEAR REACTOR ENGINEERING

Credit 3 hrs. Fall. 3 Lect. Prerequisite, consent of instructor. Primarily for second and third year graduate students. 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 Engineering* by Bonilla.

8334. NUCLEAR ENGINEERING SEMINAR

Credit 3 hrs. Spring. Prerequisite 8333. A group study of a reactor systems analysis or a reactor safeguards report. Emphasis on the interplay of requirements of safety and economics in the design of nuclear power systems.

8336. NUCLEAR MATERIALS

Credit 3 hrs. Spring. 3 Lect. Prerequisites, Materials Science, Physical Chemistry, or equivalent and consent of instructor. At level of courses for the M.Eng. degree, for example, M.Eng. (Nuclear). Same as Materials Science 6872.

[8342. READING COURSE IN RADIOCHEMISTRY]

Not offered 1966–67.

8351. NUCLEAR MEASUREMENTS LABORATORY

Credit 3 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.

8352. ADVANCED NUCLEAR AND REACTOR LABORATORY

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.

ENVIRONMENTAL SYSTEMS ENGINEERING

(For descriptions of courses see the section "Civil Engineering.")

2633. ENVIRONMENTAL SYSTEMS ENGINEERING I

Credit 3 hrs. 3 Lectures. Fall. For description, see 2517.

2634. ENVIRONMENTAL SYSTEMS ENGINEERING II

Credit 3 hrs. Spring. For description, see 2518.

2635. SIMULATION OF WATER RESOURCE SYSTEMS

Credit 3 hrs. For description, see 2521.

2636. SEMINAR IN WATER RESOURCES SYSTEMS ANALYSIS

Credit 4 hrs. Spring or fall. For description, see 2547.

2933. ENVIRONMENTAL SYSTEMS ENGINEERING I

Credit 3 hrs. 3 Lectures. Fall. For description, see 2517.

2934. ENVIRONMENTAL SYSTEMS ENGINEERING II

Credit 3 hrs. Spring. For description, see 2518.

2935. SIMULATION OF WATER RESOURCE SYSTEMS

Credit 3 hrs. For description, see 2521.

2936. SEMINAR IN WATER RESOURCES SYSTEMS ANALYSIS

Credit 4 hrs. Spring or fall. For description, see 2547.

INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

Service Courses

[9101. INDUSTRIAL ORGANIZATION AND MANAGEMENT]

Credit 3 hrs. Spring. 3 Lect. Management of an industrial enterprise; internal organization; effect of type of product, methods of manufacture, size of enterprise, and personnel involved; types of enterprises; plant location; centralization and decentralization trends; diversification and specialization; growth of industry. Not offered in 1966–67.

9110. INTRODUCTION TO INDUSTRIAL ENGINEERING

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.

9153. ENGINEERING ECONOMIC ANALYSIS

Credit 3 hrs. Fall. 2 Rec., 1 Comp. An introduction to underlying economic principles and phenomena associated with engineering projects. Basic accounting and cost control principles and procedures will be presented initially as a frame of reference for a discussion of the more profound problems relating to the engineer's role as consultant on matters of investment and operations. In addition to the necessary accounting, topics will include cost concepts, profit-volume relationships and analysis, make-buy problems, minimum cost models, replacement and renewal models, etc.

9170. INTRODUCTORY ENGINEERING STATISTICS

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 hypotheses; 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

Credit 1 hr. Fall. 1 Lect. 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.

9302. MANUFACTURING PROBLEMS

Credit 2 hrs. Spring. 1 Lect. plus numerous plant visits. A course to give the student an awareness of the industrial environment with particular reference to processing situations and techniques; the realization of the physical meaning and magnitude of such problems as found in inventory, capacity, replacement, and maintenance to suggest a few problem areas. Engineering reports and writing will also be discussed with formal reports required based on the plant visits to be made.

9303. INDUSTRIAL ENGINEERING LABORATORY

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

Credit 4 hrs. Fall. 3 Lect., 1 Comp. Prerequisites, 9350 and 9370, or equivalent. This is a problem oriented course concerned with 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.

9311. INDUSTRIAL ENGINEERING DESIGN

Credit 4 hrs. Spring. 2 Lect., 2 Comp. Prerequisites, 9310, 9320. An introduction to engineering design with emphasis on applications in industrial engineering. All elements of the design process will be covered including problem definition, feasibility, the determination of inputs and restraints, synthesis, analysis, and evaluation. Study will range from the design problems of the single workplace to the design of complex systems including manufacturing, transportation, and distribution facilities as typical systems problems.

9320. ANALYTICAL METHODS IN INDUSTRIAL ENGINEERING

Credit 4 hrs. Fall. 3 Lec.-Rec., 1 Comp. Prerequisite, 9350. 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. Introduction to inventory and queueing analysis.

9350. COST ACCOUNTING, ANALYSIS, AND CONTROL

Credit 4 hrs. Fall. 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

Credit 4 hrs. Fall. 3 Lec.-Rec., 1 Comp. Prerequisite, Math. 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

Credit 4 hrs. Spring. 3 Lec.-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

Credit 3 hrs. Spring. 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 also 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 Industrial Engineering and Operations Research. Other qualified students will be admitted only if section sizes permit it.

9460. INTRODUCTION TO PROBABILITY THEORY WITH ENGINEERING APPLICATIONS

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

9470. INTRODUCTION TO STATISTICAL THEORY WITH ENGINEERING APPLICATIONS

Credit 4 hrs. Spring. 3 Lect., 1 Rec.-Comp. Prerequisites, 9360, 9460. This course covers the same topics as 9370 described above. The lectures are held concurrently with 9370. The recitation-computing session is independent of the 9370 recitations.

9481. INTRODUCTION TO COMPUTER SCIENCE (Comp. Sc. 401)

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]

Credit 3 hrs. Spring. 3 Lec.-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. Not offered in 1966–67.

9510. WORK DESIGN AND MEASUREMENT

Credit 3 hrs. Fall. 2 Rec., 1 Lab. Intended for graduate students but open to qualified undergraduates. Prerequisite, 9310 or permission. An advanced course in the analysis and design of man-micro systems and man-machine micro systems. Advanced statistical treatment of work measurement design, variables measurement, and work sampling; mathematical and statistical treatment of model design, standard data, control, and standards maintenance; study of the micro-systems design problem, including emphasis on the behavioral aspects and wage incentives.

9511. MANUFACTURING ENGINEERING

Credit 3 hrs. Fall. 1 Lect., 1 Rec.-Comp. Intended for graduate 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.

9512. STATISTICAL METHODS IN QUALITY AND RELIABILITY CONTROL

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 9170 or equivalent. A basic course primarily for undergraduates presented from an engineering standpoint. Control concepts; control chart methods for attributes and for variables; process capability analysis; attributes acceptance sampling plans and procedures; double and multiple sampling inspection; elementary plans and procedures for variables; acceptance-rectification procedures; basic reliability concepts; exponential and normal distributions as models for reliability application; 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]

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Elective for graduate students and qualified undergraduates. Prerequisite, 9320 and 9370 or permission. 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 in 1966-67.

9521. PRODUCTION PLANNING AND CONTROL

Credit 4 hrs. Spring. 3 Rec., 1 Comp. Required of professional degree graduate students but open to others and to qualified undergraduates. Prerequisite, 9360, and 9320 or equivalent. 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 and statistical methods for performing these functions; however, the empirical systems and procedures in common use will also be discussed and evaluated.

9522. OPERATIONS RESEARCH I

Credit 3 hrs. Fall. 3 Lec.-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

Credit 3 hrs. Spring. 3 Lec.-Rec. Prerequisites, 9360 or 9170, or permission of the instructor. Not open to students who have had 9326. 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

Credit 3 hrs. One 2-hr. meeting a week. 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.

9525. FLOW AND SCHEDULING IN NETWORKS

Credit 3 hrs. Spring. 3 Lec.-Rec. Elective for graduate students. Network analysis for continuous static flow; feasibility theorems, capacity determination, minimal cost operation. Sequencing models for deterministic discrete flow networks. Determination of capacity, routing and discipline for networks of queues.

9526. MATHEMATICAL MODELS — DEVELOPMENT AND APPLICATION

Credit 4 hrs. Fall. 3 Lec.-Rec., 1 Comp. Prerequisites, 9311 and 9320 or permission of the instructor. Required of professional degree graduate students, elective for others. This course will examine in some detail both probabilistic and deterministic models used in industrial engineering work. An examination and study of some of the standard models found in the literature will be made.

9530. MATHEMATICAL PROGRAMMING

Credit 3 hrs. Fall. 3 Lec.-Rec. Prerequisite, permission of the instructor. Intended for graduate students. Theory, methods, computational techniques, and applications of mathematical programming. Classical constrained maximization and Lagrange multipliers. Linear programming; simplex method and variations; the dual and the dual simplex method; transportation programming. Integer programming. Quadratic and convex programming. Linear and quadratic assignment programming.

9531. DYNAMIC PROGRAMMING

Credit 3 hrs. Spring. 3 Lec.-Rec. Prerequisite, permission of the instructor. Intended for graduate students. Topics discussed will be drawn from the recent technical literature. Emphasis will be placed on the analytical aspects of dynamic proramming, although some computational questions will also be discussed.

9539. SELECTED TOPICS IN MATHEMATICAL PROGRAMMING

Credit 3 hrs. Spring. 3 Lec.-Rec. Prerequisite, 9530. Topics will be selected from such areas as non-linear, stochastic, and semi-infinite programming. Usually offered in even numbered years.

9550. ENGINEERING ECONOMIC ANALYSIS

Credit 3 hrs. Fall. 3 Lec. Intended for incoming graduate students only. An intensive accelerated survey of financial and managerial accounting and engineering economics. Use of cost information for financial reporting, cost control and decision making. Specific topics include: theory of double-entry accrual accounting as background for subsequent material; bookkeeping is deemphasized. 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 including the MAPI formulas; handling of risk and uncertainty.

9551. ADVANCED ENGINEERING ECONOMIC ANALYSIS

Credit 3 hrs. Spring. 3 Lec. Intended for graduate students. Pre-requisite, 9311 or equivalent. Topics include: Brief review of use of cost information for financial reporting, cost control and decision making. Intensive discussion of capital investment planning procedures. Problems in project ranking including use of payoff period, present worth, internal rate of return and MAPI urgency rating. 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

Credit 3 hrs. Spring. 2 Rec., 1 Comp. Intended for graduate students but 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

Credit 3 hrs. Fall. 2 Rec., 1 Comp. Intended primarily for graduate students. 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

Credit 3 hrs. Fall. 3 Lec.-Rec. Intended primarily for graduate students but open to qualified undergraduates. Prerequisites, 9360 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. Usually offered in even numbered years.

9563. SELECTED TOPICS IN THE THEORY OF QUALITY AND RELIABILITY CONTROL

Credit 3 hrs. Spring. 3 Lec. Intended for graduate students but open to qualified undergraduates. Prerequisite, 9370 or the equivalent. This course will concentrate on 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. Usually offered in odd numbered years.

9564. SEQUENTIAL DECISION AND CONTROL PROCEDURES

Credit 3 hrs. Spring. 3 Lec. Elective for graduate students. Prerequisites, 9560 and permission of the instructor. Markovian sequential control processes will be discussed with attention concentrated on the problem of existence of optimal control strategies. The recent work of C. Derman and D. Blackwell will be intensively studied. Usually offered in even numbered years.

9570. INTERMEDIATE ENGINEERING STATISTICS

Credit 3 hrs. Spring. 2 Rec., 1 Comp. Intended for graduate students but open to qualified undergraduates. Prerequisite, 9170 or permission. 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]

Credit 4 hrs. Fall. 2 Rec., 1 Comp. Intended for graduate students. Prerequisite, 9370 or 9570, or permission. 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. Not offered in 1966–67.

9572. STATISTICAL DECISION THEORY

Credit 3 hrs. Fall. 3 Rec. Intended for graduate students. Prerequisites, 9370 or 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.

9573. STATISTICAL MULTIPLE DECISION PROCEDURES

Credit 3 hrs. Spring. 2 Rec., 1 Comp. Intended for graduate students. 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.

[9574. EMPIRICAL TIME SERIES ANALYSIS]

Credit 3 hrs. Fall. 3 Lec. Intended for graduate students but open to qualified undergraduates. Model fitting and prediction theory; correlation analysis; spectral analysis of univariate and multivariate time series. Not offered in 1966–67.

9579. SELECTED TOPICS IN INDUSTRIAL STATISTICS

Credit 3 hrs. Either term. 2 Rec., 1 Comp. Intended for graduate students. Prerequisite, 9570 or permission. Selected topics chosen from such fields as nonparametric statistical methods, sequential analysis, multivariate analysis. Offered as required.

9580. DIGITAL SYSTEMS SIMULATION

Credit 4 hrs. Fall. 2 Lect., 1 Rec. Required of professional degree graduate students and open to others and qualified undergraduates. 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 the CLP and SIMSCRIPT languages. Problems in the design of effective investigations using simulation; statistical considerations when sampling from a simulated process.

9582. DATA PROCESSING SYSTEMS

Credit 3 hrs. Fall. 1 Lec., 1 Comp. Prerequisite, 9381 or permission. 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

Credit and sessions as arranged. Either term. Elective for qualified undergraduate and graduate students. 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 department.]

9591. INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH GRADUATE SEMINAR

Credit 1 hr. Both terms. A weekly 1½ hr. meeting. For graduate students. Discussion and study of assigned topics of importance in the field.

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

Variable credit. A normal requirement of 6 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 department.

Special Courses

A policy of the department is to attempt each year to include as a visiting professor on its staff some person, often from abroad, who has been making outstanding contributions to the field. Such persons usually offer special graduate level courses or seminars covering the specialized areas with which they have been associated.

MATERIALS SCIENCE AND ENGINEERING

6031. STRUCTURE OF MATERIALS (MATERIALS SCIENCE I)

Credit 3 hrs. Fall. 3 Lect.-Rec. Prerequisite, 6211. Elements of crystallography. Projections. Techniques for studying crystal structures. Techniques for studying micro-structure. Phase and constitutional diagrams. Morphology of microstructure. Nonequilibrium microstructures. Techniques for studying defect structures. Geometry and energetics of point, line and plane defects. Structures produced by thermal and mechanical treatments. Twin and martensite structures.

6032. MECHANICAL PROPERTIES OF MATERIALS (MATERIALS SCIENCE II)

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 6301, 6211. Elastic, plastic, and fracture phenomena in solids, including yielding, strain hardening, brittle fracture, creep and fatigue.

6033. STRUCTURE OF MATERIALS LABORATORY I

Credit 2 hrs. Fall. Lab. Experiments designed to demonstrate basic techniques and ideas in crystallography, x-ray diffraction, optical metallography, electron transmission metallography and quantitative metallography.

6034. STRUCTURE OF MATERIALS LABORATORY II

Credit 2 hrs. Spring. Lab. Continuation of 6033.

6035. THERMODYNAMICS AND FLUID MECHANICS

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

6036. THERMODYNAMICS AND FLUID MECHANICS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 6035. Applications of thermodynamics and fluid flow concepts to condensed systems, including selected extractive and refining processes. Topics also include phase equilibria, phase diagrams, solutions, surfaces and interfaces and corrosion.

6041. KINETICS (MATERIALS SCIENCE III)

Credit 3 hrs. First offered *Fall* 1967. 3 Lect. Prerequisite, 6032. An introduction to the kinetics of atomic transport and transformations in solid materials. Atomistic theory of thermally activated rate processes: diffusion; 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 thermally activated and martensite type. Solid state capillary phenomena. Oxidation and corrosion.

6042. ELECTRICAL AND MAGNETIC PROPERTIES (MATERIALS SCIENCE IV)

Credit 3 hrs. First offered *Spring* 1968. 3 Lect. Prerequisite, 6041. 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

Credit 3 hrs. Fall-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. Students are required to complete a limited number of experiments each term.

6045. MATERIALS PROCESSING I (MECHANICAL)

Credit 3 hrs. Fall. 3 Lect. Replaces 6443. 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)

Credit 3 hrs. Spring. 3 Lect. Replaces 6442. Recovery and refining of metals. Production of ferrous and non-ferrous alloys. Manufacture and utilization of refractories.

6210. MATERIALS SCIENCE

Credit 3 hrs. Fall-Spring. 2 Lect., 1 Lab., 1 Rec., alternate weeks. First offered 1967. Selected topics in physical chemistry and materials science for engineering students. The states of matter and the relation between molecular structure and physical properties. Equilibria in homogeneous and heterogeneous systems. Electrochemistry. Principles underlying structure, properties, and behavior of materials.

6211. MATERIALS SCIENCE

Credit 3 hrs. Spring. 2 Lect., 1 Rec.-Lab. Prerequisite Chemistry 276 or 285, or Engr. 6210. A survey of Materials Science including basic concepts (bonding of atoms in molecules and crystals, energy bands, ideal and nonideal crystalline and noncrystalline structures, microstructures, equilibrium and kinetic behavior of materials) and their applications in understanding selected properties of solids (such as plastic deformation, creep, fatigue, ferromagnetism, conductivity in metals, semiconductors and superconductors) and in understanding selected areas of processing of materials (such as solidification, sintering, zone refining, heat treating and cold working).

6316. MATERIALS ENGINEERING

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.

6432. MECHANICAL METALLURGY

Credit 3 hrs. Spring. Not offered after 1967. 3 Lect. Prerequisites 6301, 6311. Elastic, plastic, and fracture phenomena in metallic solids, including yielding, strain hardening, brittle fracture, creep, and fatigue.

6435. PHYSICAL METALLURGY

Credit 4 hrs. Fall. Lect. Not offered after 1967. Prerequisites, Engineering 6302, 6311, Physics 314 or 436. Structural basis of the physical behavior of materials with emphasis on metals. Consideration of atomic basis of phase stability and resulting physical properties. The kinetics and mechanisms of phase transformations involving condensed systems; nucleation, crystal growth and solidification, diffusion, precipitation, oxidation, polyphase transformations, diffusionless transformations.

6503. MATERIALS SELECTION AND USE

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 6032 or 6432. 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.

6524. KINETICS OF REACTIONS IN SOLIDS

Credit 3 hrs. Fall. 3 Lect. Not offered after 1966. For advanced undergraduates. Considers rate theory, transport processes, irreversible thermodynamics and their applications.

6551. PRODUCTION OF METALS AND CERAMICS

Credit 3 hrs. Fall. 3 Lect. Prerequisite, 6046 or consent of instructor. Discussions and calculations concerning fuels, fluid flow, heat flow, roasting and sintering, gas cleaning, and application of thermochemical data to metallurgical processes. Production and utilization of refractories.

6552. MATERIALS ENGINEERING (CASE STUDIES)

Credit 3 hrs. Spring. Engineering problems which involve mechanical, chemical, electrical, thermal, and aerodynamic design specifications are reviewed as examples of materials selection processing, and use. The case study method is used to evaluate designs, investigate service failures, and select suitable materials and processing techniques. Students make engineering analyses and propose materials for specific applications.

6553–6554. PROJECT.

Credit 3 hrs. Fall-spring. Research on a specific problem in materials or metallurgical engineering.

6555. MATERIALS PROCESSING

Credit 3 hrs. Spring. 3 Lect. An extension of Engineering 6045, emphasizing recent engineering developments in materials processing.

6612. SELECTED TOPICS IN DIFFRACTION

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 6611. 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 by 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.

6662. REFRACTORY MATERIALS

Credit 3 hrs. Spring, alternate years, not offered 1966–67. 2 Lect., 1 Lab. The lectures review the crystallography, rheology, and engineering characteristics of refractory metals (tungsten, molybdenum, columbium, and tantalum); graphites; refractory oxides (magnesia, aluminia, zirconia, beryllia and thoria); and the refractory compounds (carbides, nitrides, borides, and beryllides). Laboratory demonstrations supplement the lectures, illustrating plasma and high temperature techniques, and electron beam applications. Research laboratories actively involved in studying these materials are visited.

6669. INTRODUCTORY TO PHYSICAL CERAMICS

Credit 2 hrs. Spring, alternate years, offered 1966–67. The properties and behavior of ceramics as single and polycrystalline non-metallic inorganic materials, and as composites will be reviewed based on crystal structure, atom mobility, and structural imperfections. The surface effects, interfaces, composition, and microstructure of ceramics will be studied as a background for their behavior during sintering and forming and as thermal, electrical and mechanical properties, with discussions on nucleation, crystal and grain growth and vitrification.

6762. PHYSICS OF SOLID SURFACES

Credit 3 hrs. Coordinated with EP 8262 in spring term. 3 Lect. Graduate level. Physical principles describing the behavior of atoms, ions and electrons at surfaces or in two dimensional structures. Emphasis on applications to phenomena or matter in which the role of surfaces and interfaces is important. Equilibrium thermodynamics and statistical mechanics of interfaces. Atomistic theory of surface forces, surface energy and surface structure. Kinetics of heterogeneous processes including evaporation, condensation, adsorption and chemical reaction. Capillary effects and mechanisms of interfacial phenomena in materials. Presented at the level of review articles such as *Progress in Materials Science* and *Solid State Physics* series.

6872. NUCLEAR MATERIALS

Credit 3 hrs. Spring. 3 Lect. Prerequisite, Materials Science, Physical Chemistry, or equivalent and consent of instructor. At level of courses for the M.Eng. degree. Application of materials science to choice and design of systems used in nuclear reactors. Emphasizes effects of radiation, temperature, temperature differences, composition and structure. Brings in preparation, fabrication and use of reactor materials and components.

Graduate Core Program: Materials Science and Engineering

6601. TOPICS IN THERMODYNAMICS AND KINETICS

Credit 3 hrs. Fall. Generalization of thermodynamics to include non-chemical forms of energy. Statistical nature of entropy. Phase stability. Defect equilibria. Thermodynamics of solutions, surfaces and interfaces. Reaction kinetics. At the level of Slater, *Introduction to Chemical Physics;* Guggenheim, *Thermodynamics.*

6602. PHASE TRANSFORMATIONS

Credit 3 hrs. Spring. Diffusion. Spinodal decomposition. Nucleation theory. Diffusional growth. Formal theory of nucleation and growth transformations. Diffusionless transformations. Applications of the theory to specific changes in real materials. At the level of Christian, *Phase Transformations.*

6603. CRYSTAL MECHANICS

Credit 3 hrs. Fall. Crystal symmetry. Vector field and tensor fields, lattice deformation and fault crystallography. Reversible tensor properties of crystals. Relationships between different tensor properties. Crystal elasticity, elastic waves and polymer elasticity. Lattice dynamics. Thermophysical properties. Irreversible tensor properties. Coupling of transport phenomena. Higher order effects. At the level of Nye, *Physical Properties of Crystals,* Born and Huany, *Dynamical Theory of Crystal Lattices* and Smith, *Wave Mechanics of Crystalline Solids.*

6604. DISLOCATIONS

Credit 3 hrs. Fall. Review of elementary geometrical and strain energy aspects of dislocation theory. Experimental evidence for dislocations. Dislocation elasticity. Energy considerations. Applied stresses. Point defects. Crystallographic aspects of dislocation theory, stacking faults, partials, Thompson tetrahedron and layer structures. Jogs. Strain hardening in single crystals. Mechanical twinning. At the level of Friedel, *Dislocations.*

6605. ELECTRICAL AND MAGNETIC PROPERTIES OF ENGINEERING MATERIALS

Credit 3 hrs. Fall. 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.*

6606. MECHANICAL BEHAVIOR OF MATERIALS

Credit 3 hrs. Spring. Geometry of slip in single crystals. Strain hardening and recovery. Dislocation dynamical treatment of yield and flow. Interaction of interstitial sohite atoms with dislocations. Solution hardening. Two-phase hardening. Time dependent deformation. Ductile and cleavage, fatigue, creep-rupture and stress-corrosion fracture. At the level of review articles in *Progress in Materials Science* and various conference reports.

6611. PRINCIPLES OF DIFFRACTION

Credit 3 hrs. Fall. Production of neutrons, x-rays, absorption, scattering, Compton effect. Diffraction from periodic lattices, crystal symmetry, single crystal and powder techniques. Fourier methods, thermal vibrations 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.

MECHANICAL ENGINEERING

The courses in mechanical engineering are listed under the following headings: General, Engineering Design, Materials Processing, and Thermal Engineering.

General

3051. A.S.M.E. CORNELL UNIVERSITY SECTION

Credit 1 hr. Students who are entering the School of Mechanical Engineering are urged to become members of the Cornell University section of the American Society of Mechanical Engineers. The meetings of the Society, however, are open to all. Attendance at any twelve section meetings entitles the members to one hour elective credit; however, only one credit hour may be earned in this manner. Application for membership should be made in October of each year at the Mechanical Engineering office or to the faculty adviser of the student section.

3053. MECHANICAL ENGINEERING LABORATORY

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

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

Credit 3 hrs. Spring. 1 Lect., 2 Design Periods. Prerequisite, 3054 or equivalent. Intended for graduate students. 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

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.

Engineering Design

See also Courses 3054, 3055, 3090 under GENERAL above.

3115. CREATIVE SKETCHING

Credit 1 hr. Fall. 1 Lect. The sketch is the graphic tool of creative thought. Exercises to stimulate creative ability follow basic training of eye and hand for form awareness and sketching proficiency.

3116. INTRODUCTION TO INDUSTRIAL DESIGN

Credit 3 hrs. Fall. 2 Lab. Prerequisite, permission. Readings; abstract and applied design problems which investigate and apply the interrelationships existing between form, function, and materials.

3190. SPECIAL INVESTIGATIONS IN INDUSTRIAL DESIGN

Credit based upon actual hours of work. Lab. as required. Fall or Spring.

3321. KINEMATICS AND DYNAMICS OF MECHANISMS

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.

3322. ANALYSIS AND DESIGN OF MACHINE COMPONENTS

Credit 3 hrs. Spring. 2 Rec., 1 Design period. Prerequisites, 3321, 6316, and 3431. 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, residual stresses, and creep. Curved beams, pressure vessels, and rotors.

3324. VIBRATION AND CONTROL OF MECHANICAL SYSTEMS.

Credit 3 hrs. Fall. 2 Rec., 1 Lab. Prerequisite, 3321. 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 electro-mechanical control circuits. Modern instruments for measuring force and motion.

3331. KINEMATICS AND COMPONENTS OF MACHINES

Credit 3 hrs. Spring. 2 Lec.-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

Credit 3 hrs. Fall. 3 Rec. Intended for graduate students but open to qualified seniors. Prerequisite, 3322 or 3331. Advanced analysis of special clutches and brakes; theory of film-lubricated bearings; theories of failure and design equations; impact; simple and built-up cylinders subjected to pressure and rotation. Selected topics from advanced strength of materials. Thermal stresses and creep.

3362. MECHANICAL DESIGN OF TURBOMACHINERY

Credit 3 hrs. Spring. 3 Rec. Intended for graduate students. 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. Attention is called to a companion course 3663.

3364. DESIGN FOR MANUFACTURE

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

Credit 3 hrs. Spring. 2 Rec., 1 Comp. Prerequisite, 3321. 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

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Intended for graduate students but open to qualified undergraduates. Prerequisite, 3324 or equivalent. Further development of vibration phenomena in single- and multi-degree of freedom 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

Credit 3 hrs. Fall. 1 Rec., 2 Lab. Prerequisite, 3322 or 3331. Intended for graduate students but open to qualified undergraduates. Investigation and evaluation of methods used to obtain design and performance data. Techniques of photoelasticity, strain measurement, photography, vibration and sound measurements, balancing methods, and development techniques are studied as applied to machine design problems.

3374. CONCEPTUAL DESIGN

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 3322 or equivalent. Intended for graduate students but 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

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

3377. AUTOMOTIVE ENGINEERING

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

Credit 3 hrs. Spring. 2 Rec., 1 Lab. Intended for graduate students but open to qualified seniors. 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, non-linear systems, describing functions, sampled-data systems, and compensation techniques. Analog computer simulation and laboratory studies of hydraulic, pneumatic, and electro-mechanical components and systems.

3380. DESIGN OF COMPLEX SYSTEMS

Credit 3 hrs. Spring. Two meetings of 2 hours per week to be arranged. Intended for graduate students in engineering. Permission of professor in charge. A seminar course relying heavily on student participation in discussing frontier problems such as salt water conversion, transportation devices and systems, systems for space and underwater exploitation. 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

Credit 3 hrs. Spring. 3 Rec. Intended for graduate students. Designed to acquaint those having a general knowledge of solid and fluid mechanics with the special problems and literature currently of interest in various fields of hydrodynamic lubrication. General topics include equations of viscous flow in thin films, self-acting and externally pressurized bearings with liquid and gas lubricant films, bearing system dynamics, digital and analog computer solutions. Also selected special topics in elasto-hydrodynamic, thermo-hydrodynamic, and magneto-hydrodynamic lubrication.

3390. SPECIAL INVESTIGATIONS IN MACHINE DESIGN

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.

3391. MACHINE DESIGN SEMINAR

A one-and-a-half hour meeting approximately every other week. Required of graduate students majoring in machine design. Talks on topics of importance in the field by faculty, graduate students, and outside speakers.

3392. SPECIAL TOPICS IN ENGINEERING DESIGN

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

3420. ELEMENTS OF MATERIALS PROCESSING

Credit 2 hrs. Spring. 2 Lab. Elective for students not in Mechanical Engineering. Practical work in the laboratory with conventional machine shop and measuring equipment and techniques. Thread and gear processing. Commercial forms of materials, practices in fits, finishes and the like. Machining characteristics of ferrous, non-ferrous, and non-metallic materials.

3431. MATERIALS PROCESSING

Credit 3 hrs. Fall. 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 "non-chip" 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

Credit 3 hrs. Spring. 1 Lect., 2 Lab. Prerequisites, 3431, 6316. For graduate students and qualified undergraduates. Advanced study of mechanics of chip formation. Forces and power dynamometry. Orthogonal and three-dimensional relationships. Cutter geometry and chip control. Non-chip techniques using chemical, electrical, ultrasonic, and other media; surface characteristics; and post-process treatments.

3461. QUALITY ASSURANCE SYSTEMS

Credit 3 hrs. Spring. 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; non-contract, reflective, and radiation principles. Surface texture phenomena. True-position tolerancing and charting.

[3471. PRODUCT ENGINEERING FOR MANUFACTURE]

Credit 3 hrs. Fall. 1 Lect., 2 Lab. Prerequisites, 3431, 6316. Detailed and intensive study of component configuration for fixture constraint and tooling sequence. Cutting tools and holder designs. Economics of lot size and processing parameters. Non-machining elements of processing cycles. Pre-production and post-production analyses, process planning, machine capabilities and selection. Integrated machines, transfer concepts, automated equipment. Fixed-program capabilities. Not offered in 1966–67.

3475. NUMERICAL CONTROL OF PROCESSES

Credit 3 hrs. Spring. 2 Lect., 1 Lab.-Comp. Prerequisite, 3431. For graduate students and qualified undergraduates. 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

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

Credit 3 hrs. Fall. 3 Rec. Prerequisites, Math. 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

Credit 2 hrs. Spring. 2 Rec. Prerequisite, 3621 or equivalent. Thermodynamic properties of multiphase pure substances and real gases. Non-reactive 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

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

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 exchangers: overall heat transfer coefficients; mean temperature difference; effectiveness; design.

3626. THERMAL SYSTEMS ENGINEERING

Credit 4 hrs. Spring. 2 Lects., 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. Classification, criteria of performance, and economic considerations. Steam power plants, combustion engines, refrigerating systems, air conditioning systems, fuel cells, thermo-electric cooling and power generation.

3651. ADVANCED THERMAL SCIENCE

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

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 3625. Intended for graduate students but 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.

3653. REFRIGERATION

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.

3654. AIR CONDITIONING

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. Áir distribution. Component and system performance.

3661. ADVANCED THERMODYNAMICS

Credit 3 hrs. Fall. 3 Lect. Intended for graduate students but open to qualified undergraduates. Prerequisites, 3621, 3622, or equivalent. A rigorous and general treatment of classical thermodynamics with emphasis on mathematical developments and philosophical interpretations. The several statements of the concepts and laws of thermodynamics and equivalence proofs, the pure substance, homogeneous and heterogeneous systems. Potential functions and Maxwell's relations, availability, irreversibility, and equilibrium. Entropy flow, entropy production, and irreversible thermodynamics. The relationship between classical thermodynamics, classical statistics, quantum statistics, and information theory.

3663. TURBOMACHINERY

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.

3664. INTERMEDIATE FLUID MECHANICS

Credit 3 hrs. Spring. 3 Rec. Prerequisite, 3623. Integrated development of equations of mass, motion, and energy for fluid particles and control volumes.

Applications of these governing relations to various selected areas such as hydrodynamics and conformal transformations in ideal flows; laminar and turbulent flows; boundary layers with energy transfer; two-dimensional compressible flows; variable property flows; unsteady one-dimensional flows; other topics of current interest.

3665. TRANSPORT PROCESSES

Credit 3 hrs. Fall. 3 Rec. For graduate students and qualified undergraduate students. 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 non-opaque 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.

3667. TECHNIQUES OF THERMAL MEASUREMENT

Credit 3 hrs. Spring. 2 Lect., 1 Lab. Intended for graduate students but 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.

3669. COMBUSTION ENGINES

Credit 3 hrs. Fall. 3 Rec. Prerequisites, 3622, 3623, 3625. Introduction to combustion engines with emphasis on application of thermodynamics, fluid dynamics, and heat transfer; reciprocating combustion engines; gas turbines; compound engines; reaction engines.

3670. ADVANCED COMBUSTION ENGINES

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.

3671. AEROSPACE PROPULSION SYSTEMS

Credit 3 hrs. Spring. 3 Rec. Prerequisites, 3622, 3623, or permission of instructor. Intended for graduate students and qualified undergraduates. Application of thermodynamics and fluid mechanics to the design and performance of thermal-jet and rocket engines in the atmosphere and in space. Mission analysis in space as it affects the propulsion system. Consideration of auxiliary power supply; study of advanced methods of space propulsion.

3672. ENERGY CONVERSION

Credit 3 hrs. Spring. 3 Lect. Intended for graduate students but 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.

3673. ADVANCED FLOW MEASUREMENT

Credit 3 hrs. Fall. 2 Lect., 1 Lab. Intended for graduate students but 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.

3674. STATISTICAL THERMODYNAMICS

Credit 3 hrs. Fall. 3 Rec. Prerequisites, 3622, 3623, or equivalent. Kinetic theory of state and transport properties of gases. Statistical mechanics and thermodynamic probability. Multi-component systems in equilibrium, and introduction to non-equilibrium flows.

[3680. ADVANCED CONVECTION HEAT TRANSFER]

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. Not offered in 1966–67.

3681. RADIATIVE TRANSFER

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 3665 or consent of instructor. Theory of radiative transfer of heat. Absorption and scattering; differential approximation; surface interactions. Application to atmospheres, steady and transient slab problems; effects on shock and sound wave structure, and hypersonic flow problems. Some assignments to review current literature.

[3682. SEMINAR IN HEAT TRANSFER]

Credit 3 hrs. Spring. Two meetings of 2 hours per week 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. Not offered in 1966–67.

3683. VISCOUS FLOW THEORY

Credit 3 hrs. Fall. 3 Rec. Prerequisite, 3664 or permission of instructor. Intended for graduate students. Stress and rates of deformation tensors, derivation of the Navier-Stokes equations. Exact solutions, very slow motion, boundary layers, Tollmien-Schlichting and Taylor instability, turbulence.

3690. SPECIAL INVESTIGATIONS IN THERMAL ENGINEERING

Fall-spring. Credit by arrangement. Intended either for informal instruction to a small number of students interested in work to supplement that given in regular courses or for a student to pursue a particular investigation outside of regular courses. Permission of the department required for registration.

NUCLEAR SCIENCE AND ENGINEERING

(For descriptions of courses see the section "Engineering Physics.")

THEORETICAL AND APPLIED MECHANICS

211. MECHANICS OF RIGID AND DEFORMABLE BODIES I

Credit 4 hrs. Fall-spring. 1 Lect., 2 Rec., 1 Comp.-Lab. Co-registration in Math. 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. (Evening prelims.)

212. MECHANICS OF RIGID AND DEFORMABLE BODIES II

Credit 4 hrs. Spring. 1 Lect., 2 Rec., 1 Comp.-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. (Evening prelims.)

[900. AUTOMATA (MATH. 390)]

Credit 3 hrs. Spring. 3 Rec. Prerequisite, Math. 293–294 or Math. 221–222, or equivalent. Both the engineering and mathematical aspects of automata will be introduced. Examples of mathematical topics: Finite-state machines, neural nets, input-output machines. Turing machines, computability. Examples of engineering topics: Machines that learn, adaptive systems, pattern recognition, self-reproducing and self-repairing machines, system reliability, threshold logic systems, biological models, heuristic programming, industrial and technological applications, progress in devices, automatic language translation, cybernetics and robots. Not offered 1966–67.

1150. ADVANCED ENGINEERING ANALYSIS I

Credit 3 hrs. Fall. Prerequisite, Math. 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, vector fields and partial differential equations. Applications to heat flow, reaction rates, fluid flow, diffusion, dynamic response. Use of the digital computer is included.

1151. ADVANCED ENGINEERING ANALYSIS II

Credit 3 hrs. Spring. Prerequisite, 1150 or equivalent. A continuation of 1150 including partial differential equations and boundary value problems, complex variables, Laplace transformations. Applications to heat flow and diffusion, fluid flow, oscillatory systems, wave propagation. Use of the digital computer is included.

1159. EXPERIMENTAL MECHANICS

Credit 3 hrs. Spring. 1 Rec., 2 Lab. Primarily for graduate students and qualified undergraduates. Brittle coating method of experimental stress analysis. Electrical resistance type strain gages, including factors influencing alloy sensitivity, gage construction, gage factors, stress gages. Instrumentation for static and dynamic strain gage work including a brief coverage of amplifiers, galvanometers, recorders, and oscilloscopes. Photoelastic methods of stress analysis, photostress.

1160. APPLIED MECHANICS OF SOLIDS

Credit 3 hrs. Fall. 3 Lect. Graduates and qualified undergraduates. A unified approach to elastic, plastic and time dependent material behavior, with special emphasis on the relationship between the physical aspects of the subject and mathematical theory. Kinematics of the continuum, balance of momentum, stress hypothesis, compatibility, boundary conditions, uniqueness, extremum principles including energy methods, constitutive equations. Special topics selected from finite elasticity theory, Stokesian fluids, plasticity, linear visco-elasticity, hypoelasticity.

1162. THEORY OF VIBRATION

Credit 4 hrs. Fall. 3 Lect., 1 Lab. Prerequisite, 1180 or equiv. or consent of instructor. Graduates and qualified undergraduates. Vibration of lumped systems including free and forced vibration, damping, impedance methods, resonance, vibration isolation. Matrix methods. Continuous systems including strings, membranes, torsion and bending of beams, plates. Rayleigh-Ritz Method. Impact and transient response. Applications include vibrations of structures and machine elements.

1163. APPLIED ELASTICITY

Credit 3 hrs. Fall. 3 Lect. Graduates and qualified undergraduates. 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.

1164. THEORY OF ELASTICITY I

Credit 3 hrs. Spring. 3 Lect. General analysis of stress and strain. Plane stress and strain. Airey's stress function solutions using Fourier series, Fourier integral, and approximate methods. St. Venant and Michell torsion theory. Simple three-dimensional solutions. Bending of prismatical bars. Axially loaded circular cylinder and half space.

[1165. THEORY OF ELASTICITY II]

Credit 3 hrs. Spring. 3 Lect. Graduate students. 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. Not offered 1966–67.

1166. STRESS WAVES IN SOLIDS

Credit 3 hrs. Spring. 3 Lect. Prerequisites, 1162, 1163, or equivalent. Graduate students. 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.

1167. THEORY OF PLATE AND SHELL STRUCTURES

Credit 3 hrs. Spring. 3 Lect. Graduate students and qualified undergraduates. Analysis of deformation and stress in plates and flat slabs under transverse loads. Various boundary conditions. Numerical methods. Membrane stresses and displacements in shells under various loading. Bending theory of shells. Applications to shell-type structures such as submarines, aerospace structures shell roofs, pressure vessels.

1168. THEORY OF PLASTICITY

Credit 3 hrs. Spring. 3 Lect. Graduate students and qualified undergraduates. 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 cutting, stress analysis in metals and soils. Yield hinges. Limit analysis. Shakedown of simple statically indeterminate members.

[1169. THEORY OF ELASTIC AND INELASTIC STABILITY]

Credit 3 hrs. Fall. 3 Lect. Graduate students and qualified undergraduates. General criteria for stability of static and dynamic elastic and inelastic structures. Energy methods. Buckling of columns, plates and shells under conservative and nonconservative loading. Post-buckling behavior of technologically important structural elements. Not offered 1966–67.

1170. ADVANCED DYNAMICS

Credit 3 hrs. Spring. 3 Lect. Graduate students and qualified undergraduates. Newton's equations of motion for a system of masses, their solution, momentum, energy. Systems with variable mass, rocket equations. Variational principles of mechanics, d'Alembert's principle, Lagrange's equations, Hamilton's equations. Stability of motion, Liapunov's method. Rigid body motion, Euler's equations, tops, gyroscopes. Theory of small oscillations.

[1171. ARTIFICIAL SATELLITE THEORY]

Credit 3 hrs. Fall. 3 Lect. Graduate students and qualified undergraduates. Potential of earth; two-body problem; Hamilton Jacobi theory; orbit about spherical and nonspherical earth; Von Zeipel's method; vector theory of perturbations; Hansen's method; atmospheric drag and solar radiation effects on orbit; charged satellite in earth's magnetic field; lunar and solar perturbations; orbits of lunar satellites; attitude control of satellites. Not offered 1966–67.

[1172. SPACE FLIGHT MECHANICS]

Credit 3 hrs. Spring. 3 Lect. Graduate students and qualified undergraduates. Three-body problem; regularization; Jacobi integral; restricted three-body problem; Hill curves; libration points and stability; motion in cislunar space; interplanetary trajectories; space navigation; limiting problems in space travel; theory of optimal trajectories; Pontryagin maximum principle; rendezvous problems. Not offered 1966–67.

[1175. OSCILLATIONS IN NONLINEAR SYSTEMS]

Credit 3 hrs. Spring. 3 Lect. A study of the methods of analysis of nonlinear electrical and mechanical systems. Theory of differential equations, phase plane analysis, stability criteria, comparison between linear and nonlinear methods. Equations of van der Pol, Duffing, Mathieu, Floquet, Hill. Poincaré-Bendixson theorem, orbital stability. Methods of van der Pol, Poincaré, Kryloff and Bogoliuboff, Galerkin, Ritz, harmonic balance, equivalent linearization, graphics, perturbations. Hysteresis. Application of Banach Space techniques. Not offered 1966–67.

1180. METHODS OF APPLIED MATHEMATICS I

Credit 3 hrs. Fall. 3 Lect. Prerequisite, one-semester course in ordinary and partial differential equations. Ordinary differential equations; series; orthogonal functions and Sturm-Liouville theory; Green's function; Fourier and Laplace transforms; functions of several real variables; vector analysis; matrices; partial differential equations; with application to engineering problems.

1181. METHODS OF APPLIED MATHEMATICS II

Credit 3 hrs. Spring. 3 Lect. Prerequisite, 1180. Continuation, from 1180, of partial differential equations; complex variable; tensor analysis; calculus of variations; with application to engineering problems.

1182. METHODS OF APPLIED MATHEMATICS III

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, electro-magnetics.

1183. METHODS OF APPLIED MATHEMATICS IV

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.

1184. NUMERICAL METHODS IN ENGINEERING

Credit 4 hrs. Fall. Prerequisite, 1181 or equivalent. Methods for obtaining numerical solutions to problems arising in engineering and for expressing analytical solutions numerically. Accelerating convergence of sequences and series; continued fractions, quotient-difference algorithms. Interpolation, quadrature, and solution of initial-value problems for ordinary differential equations. Least-squares and Chebyshev approximation. Iterative methods for nonlinear equations. Boundary-value problems for ordinary differential equations; quasilinearization. Direct and iterative methods for solving systems of equations; matrix inversion and eigenvalue problems. Partial differential equations of elliptic, parabolic and hyperbolic types; finite difference methods, method of characteristics, heuristic methods.

1196. RESEARCH IN THEORETICAL AND APPLIED MECHANICS

Credit as arranged. Thesis or independent research in a field of theoretical and applied mechanics. Such research must be under the guidance of a staff member.

1197. SELECTED TOPICS IN THEORETICAL AND APPLIED MECHANICS

Credit is arranged, any term. Qualified students wishing to do work in any field of theoretical and applied mechanics should register for this course after consultation with the department. Students work with appropriate members of the staff in the chosen field. Typical areas of work include theory of elastic stability, theory of plates and shells, rocket theory and design, wave propagation, elasticity, vibrations, and experimental mechanics.

FACULTY AND STAFF

James A. Perkins, A.B., Ph.D., President of the University.

Dale R. Corson, A.B., A.M., Ph.D., Provost of the University; Professor of Engineering Physics and Physics.

Andrew Schultz, Jr., B.S., Ph.D., Dean of the College of Engineering; Professor of Industrial Engineering and Operations Research.

William H. Erickson, B.S., M.S., Associate Dean of the College of Engineering; Professor of Electrical Engineering.

John F. McManus, C. E., Assistant Dean of the College of Engineering.

Paul J. Leurgans, B.A., M.S., Ph.D., Assistant Dean of the College of Engineering.

Howard G. Smith, E.E., M.E.E., Ph.D., Director of the Division of Basic Studies; Professor of Electrical Engineering (on leave, fall 1966).

Julian C. Smith, B.Chem., Chem.E., Director of Continuing Education; Professor of Chemical Engineering.

Donald F. Berth, B.S.Ch.E., M.S.Ch.E., Director of College Relations; Lecturer in Engineering.

Donald G. Dickason, A.B., Director of Engineering Admissions and Student Personnel.

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

EMERITUS PROFESSORS

Paul P. Bijlaard, C.E., Professor of Theoretical and Applied Mechanics, Emeritus.

Lawrence Adams Burckmyer, Jr., B.S., E.E., Professor of Electrical Engineering, Emeritus.

Robert Franklin Chamberlain, M.E., Professor of Electrical Engineering, Emeritus.

Roy Edwards Clark, M.E., Professor of Heat-Power Engineering, Emeritus.

Walter L. Conwell, C.E., Professor of Highway Engineering, Emeritus.

Walter Wendall Cotner, B.S., E.E., M.E.E., Professor of Electrical Engineering, Emeritus.

Casper Lehman Cottrell, A.B., Ph.D., Professor of Electrical Engineering, Emeritus.

Carl Crandall, C.E., Professor of Civil Engineering, Emeritus.

John C. Gebhard, C.E., Professor of Civil 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.

John Edwin Perry, B.S., Professor of Railroad Engineering, Emeritus.

Harold C. Perkins, M.E., Professor of Mechanics, Emeritus.

Fred Hoffman Rhodes, A.B., Ph.D., Professor of Chemical Engineering, Emeritus.

Ernest William Schoder, B.B., B.S. in Min., Ph.D., World War Memorial Professor of Experimental Hydraulics, Emeritus.

Herbert Henry Scofield, M.E., Professor of Testing Materials, Emeritus.

Robert Hermann Siegfried, M.E., Professor of Mechanical Engineering. Emeritus.

Clarence Ellsworth Townsend, M.E., Professor of Engineering Drawing, Emeritus.

Charles Leopold Walker, C.E., Professor of Sanitary Engineering, Emeritus.

VISITING PROFESSORS

Charles F. Green, A.B., A.M., Ph.D., P.E., Visiting Professor of Electrical Engineering.

Michael D. Greenberg, B.M.E., M.S., Ph.D., Visiting Assistant Professor of Theoretical and Applied Mechanics.

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