CORNELL UNIVERSITY ANNOUNCEMENTS

ENGINEERING COURSES & CURRICULA

September 17, 1963

COLLEGE OF ENGINEERING

ACADEMIC CALENDAR (Tentative)

1963–1964			1964–1965	
Sept. 21	....S	Freshman Orientation	Sept. 19	....S
Sept. 23	...M	Registration, new students	Sept. 21	...M
Sept. 24	...T	Registration, old students	Sept. 22	...T
Sept. 25	...W	Instruction begins, 1 p.m.	Sept. 23	...W
Nov. 13	...W	Midterm grades due	Nov. 11	...W
		Thanksgiving recess:		
Nov. 27	...W	Instruction suspended, 12:50 p.m.	Nov. 25	...W
Dec. 2	...M	Instruction resumed, 8 a.m.	Nov. 30	...M
		Christmas recess:		
Dec. 21	....S	Instruction suspended, 12:50 p.m.	Dec. 19	....S
Jan. 6	...M	Instruction resumed, 8 a.m.	Jan. 4	...M
Jan. 25	....S	First-term instruction ends	Jan. 23	....S
Jan. 27	...M	Second-term registration, old students	Jan. 25	...M
Jan. 28	...T	Examinations begin	Jan. 26	...T
Feb. 5	...W	Examinations end	Feb. 3	...W
Feb. 6	..Th	Midyear recess	Feb. 4	..Th
Feb. 7	....F	Midyear recess	Feb. 5	....F
Feb. 8	....S	Registration, new students	Feb. 6	....S
Feb. 10	...M	Second-term instruction begins	Feb. 8	...M
Mar. 27	....F	Midterm grades due (at 12 noon)	Mar. 26	....F
		Spring recess:		
Mar. 28	....S	Instruction suspended, 12:50 p.m.	Mar. 27	....S
Apr. 6	...M	Instruction resumed, 8 a.m.	Apr. 5	...M
May 30	....S	Second-term instruction ends	May 29	....S
June 1	...M	Examinations begin	May 31	...M
June 9	...T	Examinations end	June 8	...T
June 15	...M	Commencement Day	June 14	...M

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CORNELL UNIVERSITY

ENGINEERING COURSES AND CURRICULA

SEPTEMBER, 1963

COLLEGE OF ENGINEERING:

AEROSPACE ENGINEERING
AGRICULTURAL ENGINEERING
BASIC STUDIES
CHEMICAL ENGINEERING
CIVIL ENGINEERING
ELECTRICAL ENGINEERING
ENGINEERING MECHANICS
ENGINEERING PHYSICS
INDUSTRIAL ENGINEERING
MATERIALS AND METALLURGICAL ENGINEERING
MECHANICAL ENGINEERING

Prospective freshmen interested in engineering should write for a special illustrated booklet entitled Engineering at Cornell. *Requests should be addressed to the Announcements Office, Day Hall, Cornell University, and should mention that the writer is a prospective freshman.*

An article "What Is Engineering School Like?" is also available and may be obtained from the Office of Student Personnel, College of Engineering, Carpenter Hall.

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ENGINEERING AT CORNELL

The objective of the College of Engineering is to provide students with a combination of sound competence in mathematics, and in engineering science and technology, and a fuller and more meaningful appreciation of the humanities and social sciences within the intellectual and cultural setting of Cornell University. To attain this goal now, and to meet the future requirements of the engineering profession, the College builds upon a long Cornell tradition of significant contributions to engineering education.

Since the founding of the University, the College of Engineering has recognized the need for excellence in both undergraduate and graduate programs. Many early Cornell engineering graduates became educators who were instrumental in establishing the pattern of development of modern engineering education. Cornell, for example, granted the first doctorate in engineering in the country and also established the nation's first separate program granting degrees in electrical engineering. The introduction of the five-year undergraduate program in 1946 reflected the need for engineers to have a better foundation in basic sciences and mathematics, greater competence in engineering science and technology, and broader exposure to the humanities and social sciences than was possible in a four-year undergraduate program. Today the five-year curriculum provides flexibility for nearly 2000 undergraduates which enables them to prepare effectively either for graduate work or for engineering practice. Programs of graduate study provide opportunities for over 400 graduate students to explore new areas of technology within the atmosphere of a diverse university.

The more than 180 permanent members of the faculty reflect varied interests in the problems of education, the challenges of new fields of research, and the advancement of the engineering profession. Each year several outstanding visiting professors are attracted to the campus. In budgeted and contract research, the entire range of the profession from the phenomena of outer space to the subatomic properties of materials, and from the decision models for computer simulation to magnetohydrodynamics was investigated by members of the faculty. Such research, essential to education in an age of dynamic technological progress and change, creates opportunities for faculty to operate on the frontiers of engineering, and provides an intellectually stimulating atmosphere for students.

Nine modern buildings on the engineering campus provide over 650,000 square feet of floor space for teaching and research. Many have been the gifts of distinguished Cornell alumni:

Leroy R. Grumman '16: Graduate School of Aerospace Engineering
Franklin W. Olin '86: Chemical Engineering
Spencer T. Olin '21: Civil Engineering
Ellis L. Phillips '95: Electrical Engineering
Maxwell M. Upson '99: Mechanical Engineering
Francis N. Bard '04: Metallurgical Engineering
Walter S. Carpenter, Jr. '10: Engineering Library and Administration

The College of Engineering has in operation a nuclear reactor facility unique among educational institutions. One reactor has a moderate power core capable of being pulsed to very high power for brief periods, producing an intense pulse of neutrons for investigations of various radiation effects. In addition, the facility has a zero power critical assembly for studies of reactor design and associated problems, a gamma irradiation cell, laboratories, and classrooms. Opportunities for study and research in nuclear technology exist in such areas as nuclear metallurgical problems, fuel processing, nuclear instrumentation, activation analysis, heat transfer, radiation effects on chemical reactions, and design of reactor structures. The pulsing feature of the reactor permits special kinds of radio-isotope tracer work in biological research.

A Center for Radiophysics and Space Research is conducting radio investigations of the atmosphere, moon, Venus, Mars, and properties of space in the vicinity of the earth and near-by planets. The development of space vehicle instrumentation for the study of solar gases and the use of radio astronomy for investigating solar, galactic, and extragalactic phenomena are a few of the many projected studies of the Center. One of its major facilities, a radar antenna of 1000 foot diameter, is nearing completion at its site in Puerto Rico. Such activities provide opportunities for faculty and graduate students in astronomy, engineering physics, electrical engineering, physics, and aerospace engineering to collaborate in advancing the understanding of space, and are typical of the many interdisciplinary programs at the University.

Graduate study and research in the field of materials science, integrating the perspectives of the basic and engineering sciences are conducted in the Materials Science Center. A better understanding of the general laws governing the behavior of materials, development of methods for improving the engineering properties of materials, as well as the creation of new kinds of materials, are among the activities of this Center. Such unified teaching and research efforts will benefit both undergraduates and graduates in their instruction and laboratory work, and will enable Cornell to maintain its prominent reputation in the materials science field.

In recognition of the growing impact of computer technology on nearly every area of engineering analysis, the Cornell Computing Center has installed a Control Data 1604 system in addition to a Burroughs 220 digital computer for use by students and faculty. Special courses are offered in the principles and operation of computers, and several engineering courses make active use of these powerful computational tools in class assignments, projects, and research investigation.

In 1961, the Ford Foundation made a grant of $4,350,000 to Cornell University to advance graduate study and research in the College of Engineering. This grant has made possible the establishment of new professorships, additional research facilities, expanded financial assistance for graduate students, and other special projects within the College. The Ford Foundation grant is having a significant effect in enabling Cornell to pioneer more effectively in education and research, essential to a rapidly expanding modern technology.

Recently, five new professorships in engineering have been established: the Given Foundation Professorship endowed by the Given Foundation in memory of John La Porte Given '96, the IBM Professorship endowed by the International Business Machines Corporation, Inc., the Walter S. Carpenter, Jr.,

Professorship endowed by Walter S. Carpenter, Jr., '10, the J. Preston Levis Professorship endowed by the Owens-Illinois Glass Company Charities Foundation and J. Preston Levis '24, and the Class of 1912 Professorship endowed by the Class of 1912. These chairs are held by William R. Sears, Henry G. Booker, Henri S. Sack, Glen Wade, and George Winter, respectively.

The accelerating expansion of modern science and technology poses a complex challenge for engineering education to keep pace with the needs of the future. These programs and activities described above are but a part of the continuing efforts of every division of the College to improve undergraduate programs and to advance graduate education and research, in order to provide Cornell engineering graduates with the foundation essential for active and rewarding professional careers.

UNDERGRADUATE CURRICULA, REQUIREMENTS, AND DEGREES

Eight baccalaureate degrees are conferred in the following fields: Agricultural Engineering, Chemical Engineering, Civil Engineering, Electrical Engineering, Engineering Physics, Industrial Engineering and Administration, Mechanical Engineering, and Materials and Metallurgical Engineering.

Such degrees are conferred on candidates who have fulfilled the following requirements:

1. The candidate must have been in residence and registered in the College of Engineering for the last two terms, must have satisfied the University requirements in physical education, and must have paid his tuition and fees.
2. He must have completed to the satisfaction of the faculty of the College of Engineering all the subjects and the elective hours prescribed in the course of study as outlined by that faculty.
3. A student who transfers to the College of Engineering, after having spent one or more terms in another college of Cornell University or elsewhere, must conform to the requirements of the class with which he graduates.

The first two years of undergraduate work are essentially the same for students expecting to study chemical, civil, electrical, industrial, mechanical, materials and metallurgy, or engineering physics. The freshman and sophomore years of study are administered by the Division of Basic Studies described on pages 24–26. Choice of a specific degree program in most instances does not have to be made until the conclusion of the second year.

Any student contemplating a transfer within the College of Engineering, or another division of the University should discuss his plans first with his adviser. If he decides to transfer to another school within the College of Engineering, the student must apply to the director of that school during the term preceding the one in which he wishes to make the change. Transfers made after the beginning of the third year, while still possible, may require one or more additional terms of study in order to meet the specific degree requirements of the program to which the student has transferred. In general, transfers early in the college program result in fewer complications and less time lost.

LIBERAL STUDIES IN THE ENGINEERING CURRICULA

Each curriculum requires a minimum total of 30 credit-hours of liberal studies, including English in the freshman year. Generally these credit hours are distributed so that an elective liberal course is taken in at least six of the remaining eight terms after the freshman year. Liberal studies include humanities (English, fine arts, philosophy, literature, music, classics, and speech and drama) and social studies (economics, government, history, psychology, sociology, and anthropology).

In addition to freshman English, nine additional hours are required in humanities with at least one two-term sequence, and nine hours in social studies, also with one two-term sequence included. The six hours remaining for fulfillment of the liberal studies minimum requirement may be taken in either humanities or social studies, or in a modern foreign language, or in any combination according to the student's preference.

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 25–26) 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 in which they are interested in being admitted as special students.

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

SPECIAL UNDERGRADUATE PROGRAMS OF STUDY

GRADUATE HONORS PROGRAM

An opportunity now exists for superior students who have achieved high scholastic records during their first four years to enroll in the graduate division in their fifth year. This materially advances their graduate studies in engineering and permits such candidates to obtain graduate degrees at an earlier

date. Throughout the undergraduate years, students exhibiting special competence in individual subjects as well as strong over-all scholastic performance are enrolled in enriched course sections which provide a sound base for the program.

Qualified candidates are encouraged to discuss their interest in the program with the directors of their respective schools during their third year so that their fourth year program of studies can be modified to permit the undertaking of graduate work in engineering during their fifth year.

INDUSTRIAL COOPERATIVE PROGRAM

During the fourth term, above-average students who plan to enroll in electrical engineering, engineering physics, industrial engineering, or mechanical engineering at the beginning of the fifth term are invited to be interviewed for admission to the Industrial Cooperative Program.

The cooperative program provides three term-length work periods (about sixteen weeks each) in one of the following companies operating the plan with the University: American Electric Power Service Corporation, Anaconda Wire and Cable Company, Cornell Aeronautical Laboratory, Emerson Electric Manufacturing Company, General Electric Company, General Radio Company, the Gleason Works, International Business Machines Corporation, Philco Corporation, Procter and Gamble Manufacturing Company, Raytheon Manufacturing Company, Stromberg-Carlson Company.

The program incorporates the summer vacation periods after the fourth term into the student's work-study schedule. The cooperative student completes the regular academic study for his Bachelor's degree, pursues his work program, totaling one year in industry, and still graduates with his regular class. He remains on campus with his regular classmates except during the fifth and eighth terms. The work of these terms is taken by the student in the summer co-op term.

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

	Third year	*Fourth year*	*Fifth year*
Summer:	Fifth term courses	Industry	Eighth term courses
Fall:	Industry	Seventh term courses	Ninth term courses
Spring:	Sixth term courses	Industry	Tenth term courses

The objective of the program is educational rather than remunerative, although the student receives a substantial salary from industry during his three work periods.

The work program of each student is arranged to advance his individual interests and aptitudes within the regular activity of the company with which he is affiliated. He has no industry assignment the first summer, and he does his industrial work in one company throughout the entire program. These two requirements enable him to pursue his engineering objectives in meaningful work areas seldom available through ordinary summer placement. The individual counseling and appraisal of progress that characterize the program enable the student to pursue his studies and graduate with realistic industrial objectives.

Students are admitted to the Cooperative Program in the fourth term only. Applicants are subject to approval both by the College and by one of the co-

operating industries. Admission to this plan involves no obligation on the part of either the student or the industry with regard to future employment.

AEROSPACE ENGINEERING PROGRAM

During the fourth and fifth years, students with good scholastic records in electrical engineering, engineering physics, or mechanical engineering may elect courses in the Graduate School of Aerospace Engineering. They may carry out senior projects in the aerospace field under the direction of the School's staff. Students who elect this program graduate with an unusually sound aerospace education in addition to their broad undergraduate engineering education. These specialized aerospace studies are of a type usually reserved for graduate students.

The student planning to follow this course of studies should consult with the Director of the Graduate School of Aerospace Engineering, by the beginning of his third year in engineering so as to plan his program to best advantage.

This same program prepares the student intending to work for the Master of Engineering (Aerospace) degree. It is also a basic program, along with his other engineering course work, for the student planning study in this field beyond the Master's degree. (See page 17.)

NUCLEAR ENGINEERING PROGRAM

Students with an aptitude for applied physics and mathematics may elect a sequence of courses in the field of nuclear engineering. Completion of such an elective program provides the Bachelor's degree candidate with an exceptionally strong foundation for graduate study or for professional work in this field. Appropriate courses should be chosen to match the student's interest and should include 8301 or Physics 314, 8302, and 8351. Additions to this introductory sequence may be made in consultation with the nuclear engineering staff. Furthermore, opportunities usually exist to carry out a senior project in the nuclear engineering field.

Interested students should discuss the program with their advisers or with the Director of the Nuclear Reactor Laboratory.

GRADUATE PROGRAMS OF STUDY

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 (Chemical, Civil, Electrical, Industrial, Mechanical, Materials and Metallurgy).

THE GENERAL DEGREES

The M.S. and Ph.D. degrees are available in all the 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.

THE DEGREE OF MASTER OF ENGINEERING (AEROSPACE)

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.

PROFESSIONAL MASTERS' DEGREES

Professional degrees at the Master's level are offered in chemical, civil, electrical, industrial, and mechanical engineering, and in materials and metallurgy, and are administered by the Engineering Division of the Graduate School. These degrees are intended primarily for those persons who wish to enhance their ability in the practice of engineering, and not for those whose expected activities will be in engineering teaching or research. The student with a baccalaureate degree in an area of engineering or science deemed appropriate to his proposed field of study may become a candidate for a professional degree. These professional degrees require at least 45 credit hours of graduate-level course work, or its equivalent, in the principles and practices of the specific field. They do not require the presentation of a thesis based upon research studies. For each candidate a special curriculum of related courses, differing in content among the several professional degrees, is either prescribed or agreed upon in advance. The prospective student should consult the detailed descriptions of requirements of the various schools elsewhere in this Announcement.

The required number of credit hours in each curriculum may be reduced by allowing credit for graduate-level work completed before entry into the program, or for professional experience approved by the faculty as substantially covering the same area as any part of the curriculum, provided that the total allowance does not exceed fifteen credit hours. Such allowance for work outside the program will be granted only after the candidate is enrolled in the program, and, in order to avoid misunderstanding, no commitments concerning advanced credit can be made by prior correspondence between faculty members and prospective students. The candidate interested in coming into this program from industry should write to the director of the division of engineering he plans to enter. Under a special arrangement a student with a superior record of performance for four years of undergraduate engineering studies at Cornell may enroll in the Graduate Honors Program during his fifth undergraduate year and accumulate credits which may be applied toward an advanced degree.

The minimum time required for a Cornell student to obtain the professional Master's degree will be one term beyond the baccalaureate degree.

The professional degrees are considered to be at the five-and-one-half to six-year level of university work, requiring from one to two years of additional study beyond a four-year baccalaureate program.

COMBINED PROGRAMS
Law, Business and Public Administration, or City and Regional Planning

Qualified students may apply for admission to special programs permitting completion of both a Bachelor's degree in engineering and a graduate or advanced degree in law, business or public administration, or city and regional planning, in one year less than the normal period. Interested students should consult their advisers during their third year, in order to plan appropriate elective courses during the fourth and fifth years.

Ordinarily such a combined program, leading to two degrees, would constitute an eight-year course of study in the case of law and seven years in the case of business and public administration or city and regional planning. By choosing as electives courses acceptable to the other schools or colleges and by being permitted to count certain other courses as meeting requirements in both areas, students will be able to acquire the two degrees in the shortened period.

Arrangements for one or more such combined programs of study are possible for selected students in chemical, civil, electrical, industrial, and mechanical engineering and materials and metallurgy. Applications will be accepted at any time prior to the fifth year, but, for maximum flexibility and ease of program planning, the choice should be made as early as possible. Applications must be approved by both participating schools or colleges.

GRADUATE SCHOLARSHIPS AND FELLOWSHIPS

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 degree of M.Eng.(Aero.) should apply to the Director of the Graduate School of Aerospace Engineering.

STUDENT PERSONNEL SERVICES

STUDENT PERSONNEL OFFICE

The admission of new students, the administration of scholarships in the College of Engineering, the placement of graduates, and the compilation and maintenance of alumni records are activities of the College which are coordinated in the Student Personnel Office. The Personnel Office, in addition to other facilities, is also available at all times to students who wish to discuss any question relating to their life in the College.

STUDENT COUNSELING

In general, the counseling of students rests with the class advisers to whom the students are assigned primarily for assistance in planning and scheduling their academic work, but who will welcome students at any time to discuss other personal matters. In each school of the College, students are referred to the chairman of the scholarship committee when in financial need and to a placement adviser for assistance in vocational choice and postgraduate employment. Also, the students are free to consult with the dean, directors, department heads, and faculty, not only on matters pertinent to their education and future plans, but also on personal matters. In addition, the University's Dean of Students and staff may be consulted by students regarding their nonacademic problems.

SCHOLARSHIPS, GRANTS-IN-AID, AND PRIZES

SCHOLARSHIPS FOR FRESHMEN

Some of the scholarships listed below are paid for from the income of endowments; others derive from revolving funds established by industries, foundations, or individuals. Many of the revolving funds provide generous gifts to the University in support of the costs of educating students not covered by tuition and fees. Those gifts to the University are made in addition to the scholarship grants, and, in the list below, the amounts are indicated in parentheses following the amounts paid the students.

CHARLES R. ARMINGTON SCHOLARSHIPS IN ENGINEERING . . . Gift of Mr. and Mrs. R. Q. Armington, in memory of their son who was a student in the School of Mechanical Engineering at the time of his death in 1956. Open to men students in any branch of engineering. One scholarship annually with annual stipend up to $2000 ($1000). Tenure, not limited. Selection based on balance of academic and extracurricular interests with outstanding personal characteristics.

JOHN HENRY BARR SCHOLARSHIP . . . Gift of Mrs. Mabel R. Barr, for a deserving student to be chosen by the University from recommendations of the Cornell Club of the Lehigh Valley. Annual award, up to $2000. Tenure, not limited.

EDWARD P. BURRELL SCHOLARSHIPS . . . Gift under the will of Katherine W. Burrell, in memory of her husband. Open to men and women entering the College of Engineering. Award, up to $800 for freshman year only. Need is an important factor in selecting the winners.

GENERAL MOTORS COLLEGE SCHOLARSHIP . . . Established in 1957 by the General Motors Corporation. Available to men or women who are citizens of the United States and are entering the College of Engineering. Two scholarships annually with stipend of from $200 to $2000 ($800), depending

upon need. Tenure, unlimited. Selection based upon outstanding academic promise, general character, and financial need.

INLAND STEEL FOUNDATION SCHOLARSHIPS . . . Established by the Inland Steel Foundation. Annual award, $1500 ($1000). Tenure, not limited. Selection is based on scholastic attainment, personal characteristics, and financial need. Summer employment may be offered to recipient by the Inland Steel Company.

MARTIN J. INSULL SCHOLARSHIP . . . Gift of his wife, Mrs. Virginia Insull. Open to men entering the College of Engineering. Annual award, $1500. Tenure, not limited. Further provisions as for the McMullen Regional Scholarships (see below), except that financial need is an essential criterion.

LOCKHEED NATIONAL ENGINEERING SCHOLARSHIP . . . Established by the Lockheed Leadership Fund. Open to entering students in the College of Engineering. Annual award, tuition and fees plus $500 ($500). Tenure, unlimited. One award each year to a student who is in a field of engineering applicable to the aerospace industry and whose total personal qualities can be expected upon graduation to offer a significant contribution to the aerospace industry.

JOHN McMULLEN REGIONAL SCHOLARSHIPS . . . Gift under the will of John McMullen. Open to men entering the College of Engineering. Annual award, up to $1800. Tenure, not limited. Sixty or more scholarships awarded annually. Applicants will be selected on the basis of high scholastic achievement and other indications of qualities likely to produce leadership in engineering. Although financial need is not a factor in selecting the winners, full consideration will be given to need in fixing stipends.

OWENS-ILLINOIS SCHOLARSHIP . . . Established by Owens-Illinois. Open to men. Annual award, tuition and fees plus $125 for books and supplies in the freshman year and $100 annually thereafter ($1400). Tenure, not limited. Selection will be based on scholastic achievement, personality, and financial need. Summer employment may be offered by Owens-Illinois.

PROCTER AND GAMBLE SCHOLARSHIPS . . . Established by the Procter and Gamble Company. Open to men or women entering the College of Engineering. Annual award, tuition and fees plus $115 for books and supplies ($600). Tenure, unlimited. Selection based on academic achievement, character, and financial need.

ANNIE F. AND OSCAR W. RHODES SCHOLARSHIPS . . . Gift under the will of Oscar Lynn Rhodes in memory of his mother and father for scholarships to students in engineering. Open to freshmen. Annual award, up to $1800. Tenure, not limited. One or more scholarships to be awarded annually to students on the basis of high scholastic achievement and professional promise. Although financial need is not a factor in selecting the winners, full consideration will be given to need in fixing stipends.

ALFRED P. SLOAN NATIONAL SCHOLARSHIPS . . . Established by the Alfred P. Sloan Foundation. Open to men entering the College of Engineering. Annual award varies from a prize scholarship of $200 to as much as $2000, de-

pending upon financial need ($520). Tenure, not limited. Nine scholarships awarded annually. Applicants will be selected on the basis of high character, sound personality, leadership potential, and professional promise.

UNION CARBIDE ENGINEERING SCHOLARSHIPS . . . Established in 1960 by the Union Carbide Corporation. One scholarship awarded annually to an entering student with a preference for chemical, industrial, or mechanical engineering or materials and metallurgy. Award equal to the amount of tuition and fees plus $100 for books and supplies ($600). Tenure, not limited. Same requirements as for the McMullen Regional Scholarships.

JESSEL STUART WHYTE SCHOLARSHIP . . . Gift of Mrs. Anna Jessel Whyte in memory of her son. Open to entering students with a preference for mechanical engineering. Annual award, $1000. Tenure, not limited. Preference will be given to residents of Illinois, Iowa, Michigan, Minnesota, and Wisconsin. Further provision as for McMullen Regional Scholarships.

SCHOLARSHIPS AND GRANTS-IN-AID FOR UPPERCLASSMEN

Students in their sophomore year and beyond may apply for financial assistance through the Office of Scholarships and Financial Aid, Day Hall.

Awards are of two general types: (1) those for which the principal qualification is financial need, and (2) those for which outstanding scholastic achievement is the chief criterion. In the first category are scholarships which are essentially grants-in-aid. Eligibility extends to any student not on scholastic probation.

The second category of awards, based on high scholastic and other attainments, consist of (1) a limited number of scholarships sponsored by industrial companies, mostly for students in their last two years of study, and (2) such vacancies as may occur in scholarships of this type usually awarded to entering students and subject to renewal.

Many of the sponsoring institutions provide generous gifts to the University in support of the costs of educating students not covered by tuition and fees. Their gifts to the University are made in addition to the scholarship grants, and, in the list below, the amounts are indicated in parentheses following the amounts paid the students.

Below are the scholarships sponsored by industrial companies and foundations.

ALCOA SCHOLARSHIPS . . . Established in 1959 by the Alcoa Foundation. Open to third, fourth, or fifth year students. Five awards annually, one of which shall be for a student in materials and metallurgy. Award, $625 ($125). Tenure, one year.

ALLEGHENY LUDLUM SCHOLARSHIP . . . Established by the Allegheny Ludlum Steel Corporation. Award, $500 ($500). Tenure, three years. Awarded annually to a student in chemical engineering or materials and metallurgy, normally to a student in materials and metallurgy, with primary consideration for academic record, promise of ability, and success in his field of study. Need is a secondary factor.

CHARLES R. ARMINGTON PRIZE SCHOLARSHIP IN ENGINEERING . . . Gift of Mr. and Mrs. R. Q. Armington, in memory of their son who was a

student in the Sibley School of Mechanical Engineering at the time of his death in 1956. One scholarship annually to a student entering his fourth year in any branch of engineering, with annual stipend of $500 or more depending upon need ($1000). Tenure, two years. Recipients will be students who in their first three years of college have demonstrated outstanding qualities of personality, notably sportsmanship of a high order.

CARRIER MEMORIAL SCHOLARSHIPS . . . Established in 1961 by the Carrier Air Conditioning Company. Award, $1200. Tenure, three years. One scholarship annually to a student in his third year who has established an outstanding scholastic record, who needs financial assistance or possesses exceptional ability.

DOW CHEMICAL COMPANY SCHOLARSHIP . . . Established by the Dow Chemical Company. Award, $1000. One scholarship to be awarded annually and renewable for the fifth year to a student in chemical engineering.

FOUNDRY EDUCATIONAL FOUNDATION SCHOLARSHIPS . . . Open to all students (except freshmen) in materials and metallurgy and mechanical engineering who are interested in preparing themselves for professional engineering work in the foundry industries. Annual award, up to $600. Tenure, one or more years. Awarded on the basis of leadership, financial need, scholastic standing, and interest in foundry work.

MINNESOTA MINING AND MANUFACTURING COMPANY SCHOLARSHIPS . . . Established in 1962 by the Minnesota Mining and Manufacturing Company. One or more awards to undergraduate students. Award, not to exceed $1000. Tenure, one year.

MONSANTO SCHOLARSHIP . . . Established by the Monsanto Chemical Company. Open to fifth year students in chemical engineering and materials and metallurgy. Award based upon academic standing, interest in chemistry, and probability of success. Financial need not considered. Annual award, $1000.

NIAGARA MACHINE & TOOL WORKS SCHOLARSHIP . . . Established in 1956 by the Niagara Machine & Tool Works. Award, $1000 ($1000). Tenure, two years. One scholarship every two years to a fourth year student in mechanical engineering with principal interest in machine design and development.

SCOTT PAPER COMPANY FOUNDATION AWARD FOR LEADERSHIP . . . Established in 1954 by the Scott Paper Company. One scholarship awarded annually to an outstanding third year student in chemical, industrial, or mechanical engineering whose intention is to prepare for an industrial career. Tenure, three years. Award, $1,000 ($333.33). Recipients should have demonstrated those high qualities of intellect, personality, and physical vigor associated with the well-known "Rhodes Scholars." Financial need is not a criterion of selection.

STANDARD OIL COMPANY OF CALIFORNIA SCHOLARSHIP . . . Established in 1961 by the Standard Oil Company of California. Award, tuition. Tenure, one year. One scholarship for a mechanical engineering student in any undergraduate year.

WESTERN ELECTRIC SCHOLARSHIPS . . . Established by the Western Electric Company. Open to students in any division of the College of Engineering. Three scholarships with annual award up to $800 to be applied against the

cost of tuition, fees, and books. Tenure, one year; may be renewed. Selection based upon need and ability in fields of study related to the Company's operations.

WYMAN-GORDON SCHOLARSHIPS . . . Established in 1954 by the Wyman-Gordon Company. One scholarship awarded annually to a fourth-year student in mechanical engineering or materials and metallurgy, as the Company may designate. Award, $500 ($500). Tenure, two years.

PRIZES

Cornell University has a considerable number of funds given for the endowment of prizes to be awarded annually. Some of these prizes are open to competition by any students in the University. The publication, *Prize Competitions,* describing the prizes and the nature of the competitions, may be obtained at the Visitor Information Center, Day Hall. Prizes open to competition particularly by students of the College of Engineering are:

THE AMERICAN INSTITUTE OF CHEMICAL ENGINEERS PRIZE is a badge awarded by the School of Chemical Engineering to a junior in chemical engineering for the best scholastic record at the end of the fourth term.

THE AMERICAN SOCIETY OF TESTING MATERIALS PRIZES, consisting of six one-year memberships in the Society, are awarded to students in the College of Engineering for the highest scholastic average in materials.

THE CHARLES LEE CRANDALL PRIZES, founded in 1916 by alumni of the School of Civil Engineering. The prizes of $200 and $100 are awarded each year by a committee appointed by the Director of the School of Civil Engineering for the best papers written by students in the fifth term or above in that School, on suitable subjects, provided that both the substance and the written form of the papers submitted show real merit. The prizes were established to encourage original research, to stimulate interest in matters of public concern, and to inspire in the students an appreciation of the opportunities which the profession of civil engineering offers them to serve their fellow men as intelligent and public-spirited citizens. Papers must be submitted to the Director of the School of Civil Engineering on or before April 15 of each year.

THE FUERTES MEDALS, established by the late Professor E. A. Fuertes. The endowment provides for two gold medals. One is awarded annually by the faculty to that student of the School of Civil Engineering who is found at the end of the first term of his senior year to have maintained the highest degree of scholarship in the subjects of this course, provided he has been in attendance at the University for at least two years. The other is awarded annually by the faculty to a graduate of the School of Civil Engineering, or the recipient of a graduate degree with major in civil engineering, who has written a meritorious paper upon some engineering subject tending to advance the scientific or practical interests of the profession of the civil engineer. It is desired that papers be presented on or before April 15. If a paper is presented in printed form, it will not be received if it has been printed earlier than the preceding April 15. Neither medal is awarded unless it appears to the faculty of the School of Civil Engineering that there is a candidate of sufficient merit to entitle him to such distinction.

THE FUERTES MEMORIAL PRIZES IN PUBLIC SPEAKING, established in 1912, consist of several prizes totaling $200. They are awarded by a committee of seven judges to students in the fifth term or beyond of the Colleges of Architecture and Engineering for proficiency in public speaking.

THE HAMILTON AWARD . . . A suitably engraved Hamilton watch and letter of commendation is awarded annually to the senior in engineering who has most successfully combined proficiency in his major field of study with achievements, either academic, extracurricular, or a combination of both, in the social sciences and humanities.

THE AMERICAN INSTITUTE OF AERONAUTICS AND ASTRONAUTICS PRIZE . . . The "Student Branch Scholastic Award" of the American Institute of Aeronautics and Astronautics is presented annually to the M.Eng.(Aero.) candidate who attains the best scholastic record for that academic year. The award consists of a certificate and a two-year free technical membership in the Institute.

SIBLEY PRIZES . . . Under a gift of Hiram Sibley, made in 1884, the sum of $100 is awarded annually in several prizes to fifth year students in mechanical engineering and electrical engineering, equally distributed, who have received the highest average in the preceding four years.

THE SILENT HOIST AND CRANE COMPANY MATERIALS HANDLING PRIZE, established in 1950 by the Wunsch Foundation, is in an amount approximating $300 and is awarded for the best original paper on the subject of materials handling at the discretion of a College of Engineering faculty committee. This contest is open to undergraduate and graduate students of the College of Engineering.

THE WILLIAM WAYNE KRANTZ AWARD, established by the Class of 1961 in Electrical Engineering in memory of their classmate who died on August 6, 1960, is made to the fifth year student in Electrical Engineering who has demonstrated qualities of perseverance, ambition, courage, and unwavering desire to become an electrical engineer. Award consists of a shingle and enrollment of the winner's name on a plaque in Phillips Hall.

THE J. G. WHITE PRIZES IN SPANISH . . . Through the generosity of James Gilbert White (Ph.D., Cornell, '85), three prizes, established in 1914, each of the value of $100, are offered annually. One of the three, which is awarded to an English-speaking student for proficiency in Spanish, is open to members of the junior and senior classes in the College of Engineering who are candidates for their first degree. No candidate is eligible unless he has completed successfully two terms of work in Spanish at Cornell University.

COLLEGE HONORS AND ACTIVITIES

DEAN'S HONOR LIST

Students of the College of Engineering whose weighted average in their studies is 85.00 per cent or better are included annually in an Honor List compiled for the Dean. The honor students comprise approximately the highest tenth of all the students enrolled in the College.

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.

PUBLICATIONS

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

ENGINEERING SOCIETIES

Many meetings of the American Society of Civil 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, represents engineering student viewpoints in campus affairs, and conducts studies of the activities of the College. Upperclassmen on the council have participated in an informal tutoring program for freshmen desiring such assistance.

SOURCES OF ADDITIONAL INFORMATION

Prospective freshmen interested in engineering should write for a special illustrated booklet entitled *Engineering at Cornell.* Requests should be addressed to the Announcements Office, Day Hall, Cornell University, and should mention that the writer is a prospective freshman.

Also of interest to prospective students is an article "What Is Engineering School Like?" which may be obtained from the Office of Student Personnel, Carpenter Hall, Cornell University.

Detailed information on the following subjects is available in the *Announcement of General Information:* health services and medical care, health requirements, housing, ownership of cars, physical education, loans, part-time employ-

ment, tuition, and fees. Information on military training is available in the *Announcement of Military Training*. Both Announcements may be obtained by writing the Announcements Office, Day Hall.

Students on the Cornell campus may obtain copies of the Announcements (catalogs) at the administrative offices of the various schools and colleges.

THE PHILIP AND SADIE SPORN LOAN FUND. In addition to the University loan program open to all Cornell students, the Philip and Sadie Sporn Loan Fund is reserved specifically for engineering candidates. It is for students with considerable need. Evidence of maturity and enterprise on the part of the applicant are considered in choosing the recipients.

GRADUATE SCHOOL OF AEROSPACE ENGINEERING

GRUMMAN HALL

Aerospace engineering is the field of engineering that deals with the flight of aircraft, guided missiles, and space vehicles in the atmosphere and in the regions of space adjoining the atmosphere. The primary objective of this School is to educate selected engineering and science graduates in the scientific aspects of this field. The training is intended especially to prepare the students for research and development engineering in the aerospace industry and in related research institutions.

In the School's new quarters, superior facilities are provided for laboratory studies in fluid mechanics, aerodynamics, and gasdynamics. Members of the teaching staff and graduate students are engaged in an active program of fundamental studies in these fields. Emphasis is put upon the scientific and engineering problems of space flight, i.e., of vehicles which leave and re-enter the earth's atmosphere at extreme speeds.

PREPARATION FOR GRADUATE STUDY

The Graduate School of Aerospace Engineering will admit students holding baccalaureate degrees in any branch of engineering, physics, or mathematics, 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, and physics. In most cases, it would be well for engineering students to elect courses in intermediate or advanced physics, such as atomic and molecular physics, kinetic theory of gases, and electricity and magnetism.

It will be possible for Cornell students in the five-year undergraduate programs to complete the requirements for the degree M.Eng. (Aerospace) in one year of graduate study instead of the normal two years, if they complete a sufficient number of the required graduate courses as electives in their undergraduate programs.

MASTER OF ENGINEERING (AEROSPACE)

Students who in their undergraduate careers have demonstrated more than average ability in analytical subjects and who have shown adequate promise of carrying on graduate study successfully are eligible to apply for this program in the Graduate School of Aerospace Engineering.

Application for admission to this program 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.

The program of aerospace engineering studies is applicable to much of the standard engineering work in the aerospace industry, but 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 the progress in this field is so rapid, it is an essential objective of this program to go beyond the study of present-day practices and techniques and to prepare the student in the fundamental background and analytical methods that can be adapted to future development.

The successful completion of the work for this degree requires that the student (1) pass a series of courses or examinations in the subjects listed below; and (2) submit an acceptable Master's thesis based upon original research. The subject list constitutes a standard of accomplishment for the M.Eng. (Aerospace) candidate, but the faculty will modify the list to suit the needs, interests, and background of each individual candidate. Courses are available to permit candidates to study in any of three areas of aerospace engineering: (1) aerodynamics, (2) gasdynamics (aerophysics), and (3) aerospace structures. Active research in the first two of these areas is being carried out in the School. Research in aerospace structures is an important activity of the Department of Engineering Mechanics. The student electing to concentrate his work in this field will take a considerable portion of his electives in engineering mechanics.

Although the standard list of required subjects, together with the thesis, would ordinarily occupy four terms of graduate study, the residence requirement has been set at one year (two terms) so that students who enter the School with exceptional preparation, or who are able otherwise to pass the required examinations, may be able to qualify for the degree in one year.

If the student wishes to satisfy a requirement by examination rather than by passing a course, he should request the faculty of the School to schedule such an examination.

It is suggested that each candidate supplement his required program of courses, e.g., the standard list below, by additional courses either in aerospace engineering or in other fields of study in order to achieve a balanced program of twelve to sixteen credit hours per term.

The candidate must pass a final examination, either oral or both oral and written, administered by the faculty of Aerospace Engineering. The faculty frequently invites other members of the University staff to attend and to participate in such examinations.

STANDARD LIST OF REQUIRED SUBJECTS FOR THE MASTER OF ENGINEERING (AEROSPACE) DEGREE

	CREDIT HOURS
Engineering 1180, 1181, Mathematical Methods in Engineering I and II	6
Engineering 7101, Fundamentals of Aerodynamics	3
Engineering 7102, Fundamentals of Astronautics	3
or	
Engineering 4991, Electronic Engineering	3

	CREDIT HOURS
Engineering 7203 (or 8121) and 7204, Gasdynamics	6
Engineering 7301, Theoretical Aerodynamics I	3
Engineering 1170, Advanced Dynamics	3
Electives chosen from List A below	12

ELECTIVES: LIST A

Engineering 7206, Introduction to Magnetohydrodynamics	3
Engineering 7207, Dynamics of Rarefied Gases	3
Engineering 7208, Hypersonic-Flow Theory	2
Engineering 7302, Theoretical Aerodynamics II (Wing Theory)	3
Engineering 7303, Theoretical Aerodynamics III (Compressible Fluids)	3
Engineering 7304, Theoretical Aerodynamics IV (Viscous Fluids)	3
Engineering 1162, Theory of Vibration	3
Engineering 1163, Applied Elasticity	3
Engineering 1164, Theory of Elasticity I	3
Engineering 1165, Theory of Elasticity II	3
Engineering 1167, Theory of Plate and Shell Structures	3
Engineering 1168, Theory of Plasticity	3
Engineering 1171, Space Mechanics	3
Engineering 1172, Selected Topics in Engineering Mechanics	(arranged)
Engineering 1175, Oscillations in Nonlinear Mechanics	3
Engineering 3652, Combustion Theory	3
Engineering 4565, Electromagnetic Theory	3
Mathematics 415–6, Mathematical Methods in Physics	4, 4
Physics 318, Analytical Mechanics	4
Physics 431, Introductory Theoretical Physics	4
Physics 443, Atomic Physics and Introduction to Quantum Mechanics	4
Physics 444, Nuclear and High Energy Particle Physics	4
Physics 454, Electronic Properties of Solids and Liquids	4
Physics 510, Advanced Experimental Physics	3
Physics 571, Classical Mechanics	3
Physics 573, Electrodynamics	4

STUDY LEADING TO THE DEGREE OF Ph.D.

The current *Announcement of the Graduate School* sets forth the requirements for candidacy for the degree of Ph.D. and lists the general requirements—residence, major and minor subjects, foreign languages, qualifying examinations, and thesis. As explained in that Announcement, each candidate must complete a schedule of courses acceptable to his Special Committee.

AGRICULTURAL ENGINEERING

RILEY-ROBB HALL

A joint program administered by the Colleges of Agriculture and Engineering leads to the degree of Bachelor of Engineering (Agricultural). Students in this curriculum register in the College of Agriculture during the first four years but take courses in the Colleges of Engineering, Arts and Sciences, and Agriculture. Registration for the fifth 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 the agricultural industry—including such fields as power and machinery, structures, soil and water engineering, electrification, and the processing and handling of agricultural products.

Complete laboratory facilities for teaching and research programs in agricultural engineering and food technology are in Riley-Robb Hall. Because the Department has an active research program supported through the Cornell Agricultural Experiment Station, many students find opportunities for part-time work in research during the academic year and in summer vacations.

PRACTICE REQUIREMENT

Since agricultural engineering students are registered in the College of Agriculture for the first four years, they must meet the farm practice requirement of the College. The basic requirement is 25 units of acceptable farm experience gained at the approximate rate of one unit per week. Twelve of these units must be completed before registration for the sophomore year. The entire 25 units must be completed prior to registration in the fourth year. Unless the student has fulfilled these requirements as a prefreshman, he will usually do so during the summers between the freshman and junior years. The *Announcement of the College of Agriculture* should be consulted for details of the requirement.

A.S.A.E. STUDENT BRANCH

An active student branch of the national American Society of Agricultural Engineers is available to all students in this program. Participation in the organization is a valuable means of gaining first-hand knowledge of the professional field of agricultural engineering, and it also provides opportunities for personal development.

ELECTIVES

There are thirty hours of electives:

1. Six hours in social studies with a two-course sequence.
2. Six hours in humanities with a two-course sequence.
3. Twelve hours of electives in nontechnical courses.
4. Six hours of electives unspecified.

SCHOLASTIC REQUIREMENTS

To remain in good standing, a student must have a weighted average for the term of 70 or above. If the weighted average is 60 or higher, but less than 70, the student will be placed on probation. A student will be dropped from the program if a third consecutive term of probation is indicated or if the weighted average is below 60. In all cases, the student may appeal an action by presenting new information to the Joint Faculty Committee.

CURRICULUM . . . Bachelor of Engineering (Agricultural)

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

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 1	Mathematics 191, Calculus for Engineers	4	4	0
	Physics 121, Introductory Analytical Physics	3	3	2½
	Chemistry 103, 107, or 115, General Chemistry	3	3	2½
	English 111, Introduction to English	3	3	0
	Agr. Engineering 105, Engineering Drawing	4	2	5
	Agriculture 1, Orientation	1	1	0
	Total	18		
TERM 2	Mathematics 192, Calculus for Engineers	4	4	0
	Physics 122, Introductory Analytical Physics	3	3	2½
	Chemistry 104, 108, or 116, General Chemistry	4	4	2½
	English 112, Introduction to English	3	3	0
	Agr. Engineering 2, Introduction to Agricultural Engineering	2	1	2
	Total	16		

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

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 3	Mathematics 292, Engineering Mathematics	4	4	0
	Physics 223, Introductory Analytical Physics	3	3	2½
	Engineering 211, Mechanics of Rigid and Deformed Bodies	4	3	2½
	Animal Husbandry Elective	3	–	–
	Biology 1, General Biology	3	2	2½
	Total	17		
TERM 4	Mathematics 294, Engineering Mathematics	3	3	0
	Physics 224, Introductory Analytical Physics	3	3	2½
	Engineering 212, Mechanics of Rigid and Deformed Bodies	4	3	2½
	Chemistry 276, Introduction to Physical Chemistry	3	3	0
	Biology 2, General Biology	3	2	2½
	Agr. Engineering 220, Surveying	2	1	2½
	Total	18		

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

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 5	Engineering 6311, Material Science	4	3	2½
	Engineering 241, Electrical Science	3	2	2½
	Engineering 2701, Structural Theory I	3	4	–
	Agronomy 11, Production of Field Crops	4	3	2½
	Bacteriology 1, General Bacteriology	5	3	5
	Total	19		
TERM 6	Engineering 2002, Engineering Materials	3	2	2½
	Engineering 242, Electrical Science	3	2	2½
	Engineering 3331, Kinematics and Components of Machines	3	2	2½
	Agronomy 1, Nature and Properties of Soils	4	3	2½
	Electives	6		
	Total	19		
TERM 7	Engineering 3621, Thermal Science I: Thermodynamics	3	3	0
	Engineering 2301, Fluid Mechanics	3	3	0
	Agr. Engineering 203, Agricultural Machinery	3	2	2½
	Extension Teaching 101, Oral and Written Expression	2	2	0
	Technical Elective	3		
	Elective	3		
	Total	17		
TERM 8	Engineering 3622, Thermal Science II: Thermodynamics	3	3	0
	Agr. Engineering 221, Soil and Water Engineering	3	2	2½
	Agr. Engineering 202, Agricultural Power	3	2	2½
	Agricultural Economics 102, Farm Management	5	3	2½
	Technical Elective	3		
	Total	17		
TERM 9	Engineering 3625, Thermal Science V: Heat Transfer	4	3	2½
	Agr. Engineering 461, Materials Handling and Processes	4	3	2½
	Agr. Engineering 231, Agricultural Structures	3	2	2½
	Agr. Engineering 206, Project	3		
	Elective	3		
	Total	17		
TERM 10	Agr. Engineering 253, Special Topics in Agr. Engineering	1	1	0
	Agr. Engineering 261, Project	3		
	Electives	12		
	Total	16		
	Total for ten terms	174		

The courses of study for terms 7 through 10, for those students who matriculated in 1960 or before will be developed individually to incorporate offerings from the new curriculum.

GRADUATE STUDY

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 depending upon the student's interests and needs. 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 ranging from $2400 to $3000. For more detailed information and sample programs, contact the Graduate Field Representative. Riley-Robb Hall, Cornell University.

DIVISION OF BASIC STUDIES

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

During his freshman year the engineering student undertakes to develop his underlying competence in mathematics and in the sciences of physics and chemistry, while improving his ability to communicate through a course in English required of nearly all freshmen at the University. Through contact with senior engineering staff, both as advisers and in class discussions in a course in engineering problems and methods, the student is able to arrive at valid educational goals in line with his interest and demonstrated competence. He is made more fully aware of the range of the fields and the functions of the individual in the engineering profession. Instruction in graphics as a means of communication, some aspects of engineering economy, an introduction to elementary concepts of problem solving, and design at an elementary level based on concurrent mathematics and science courses, are also included.

During the sophomore year the student extends his knowledge of mathematics and physics and begins his study of the applications of these sciences to engineering problems in two courses taught by members of the faculty of the College of Engineering in the fields of mechanics and electrical science. He undertakes a course of physical chemistry, tying together his background in physics and chemistry at a level utilizing his strong preparation in mathematics, and laying the foundation for a subsequent course in materials in the junior year of the field of his upperclass work. He also undertakes an elective course, continuing to develop that group of liberal studies requirements, including English, that constitute approximately one-fifth of his engineering education at Cornell. Students moving toward chemical engineering delay the studies in mechanics from the sophomore to the junior year in order to establish earlier chemistry sequences during their sophomore program.

Most students select their upperclass objectives before the beginning of the spring term of their sophomore year. The professional schools specify one of the five courses of term four, for students planning to enter that specialty. This may normally be taken either during the spring term of the sophomore year or in the summer session preceding junior enrollment. Through these alternatives students find a change of objective possible as late as the beginning of their junior year.

If a student expresses his 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.

Students in underclass courses are normally enrolled in sections of the various

courses which are suitable to their individual level of achievement, and some are thus able to develop more rapidly toward the honors groups or programs of advanced study available in their professional fields. Through cooperation with the advanced placement program of the College Entrance Examination Board and departmental tests given during the 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. For superior students who have achieved advanced placement in mathematics and either chemistry or physics upon graduation from high school, it is possible for enrollment to be achieved at sophomore level through the use of the University summer session prior to their enrollment at the University in September. Students with superior performance in the freshman year are encouraged to undertake enrollment in honors sections at the sophomore level. Continued satisfactory achievement makes possible upperclass registration in the Graduate School in the Graduate Honors Program in the student's fifth year (see announcements of upperclass honors enrollment of the separate engineering schools).

The Division of Basic Studies of the College of Engineering requires all students to pass five courses, four of these with a grade of seventy or better, in order to remain in good standing in the Division. All engineering students are required to complete thirty hours of liberal studies before graduation; six credits of English and three credits of liberal elective must be completed by students in this division as part of this college requirement. (See Liberal Studies in the Engineering Curricula, page 4, for distribution requirements.)

FRESHMAN YEAR

Freshman students entering the College of Engineering in the fall of 1963 will take the following program of courses:

	CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
FIRST TERM			
Mathematics 191, Calculus for Engineers	4	4	0
Physics 121, Introductory Analytical Physics	3	3	2½
Chemistry 103, Introduction to Chemistry	3	2	3
or			
Chemistry 107, General Chemistry	3	2	3
or			
Chemistry 115, General Chemistry and Inorganic Qualitative Analysis	4	3	3
English 111, Introduction to English	3	3	0
Engineering 101, Engineering Problems and Methods I	3	2	2½
SECOND TERM			
Mathematics 192 or 192H, Calculus for Engineers	4	3	2½
Physics 122, Introductory Analytical Physics	3	3	2½
Chemistry 104, Introduction to Chemistry	3	2	3
or			
Chemistry 108, General Chemistry	4	3	3
or			
Chemistry 116, General Chemistry and Inorganic Qualitative Analysis	4	3	3
English 112, Introduction to English	3	3	0
Engineering 102, Engineering Problems and Methods II	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 chemical engineering designates, will take the following program of courses:

	CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
THIRD TERM			
Mathematics 293 or 293H, Engineering Mathematics	4	4	0
Physics 223, 225 or 227, Introductory Analytical Physics	3	3	2½
Electrical Science 241 or 243, Electrical Science I	3	2	2½
Mechanics 211, Mechanics of Rigid and Deformable Bodies I	4	3	2½
Liberal Elective	3 or 4	–	–
FOURTH TERM			
Mathematics 294 or 294H, Engineering Mathematics	3	3	0
Physics 224, 226 or 228, Introductory Analytical Physics	3	3	2½
Chemistry 276, Introduction to Physical Chemistry	3	3	0
Mechanics 212, Mechanics of Rigid and Deformable Bodies II	4	3	2½
Electrical Science 242 or 244 *	3	2	2½

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

	CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
THIRD TERM			
Mathematics 293 or 293H, Engineering Mathematics	4	4	0
Physics 223, 225 or 227, Introductory Physics	3	3	2½
Electrical Science 241 or 243, Electrical Science I	3	2	2½
Chemistry 285, Introductory Physical Chemistry	5	3	6
Chemical Engineering 5101, Material and Energy Balances	3	2	2
FOURTH TERM			
Mathematics 294 or 294H, Engineering Mathematics	3	3	0
Physics 224, 226 or 228, Introductory Analytical Physics	3	3	2½
Liberal Elective	3 or 4	–	–
Chemistry 286, Introductory Physical Chemistry	5	3	6
Chemical Engineering 5102, Equilibria and Staged Operations	3	2	2

* Civil engineering and engineering physics designates have the option of taking a liberal elective in the place of the second term of electrical science. All other engineering designates are required to take the second-term electrical science.

CHEMICAL ENGINEERING

OLIN HALL

Chemical engineering is the application of the principles of the physical sciences, of mathematics, and of engineering judgment to fields in which material is treated to effect a change in state, energy content, or composition. The major application of chemical engineering is in the process industries where raw materials are converted into useful products, such as chemicals, petroleum products, metals, rubber, plastics, synthetic fibers, foods, and paper.

Programs in chemical engineering are administered by the School of Chemical Engineering, with facilities in Olin Hall. Chemistry courses are given in the Baker Laboratory of Chemistry. Instruction in the basic principles of chemical engineering starts in the second year and extends through the fifth year. The project courses in the fifth year are designed to encourage individual work and initiative under conditions equivalent to those found in the process industries.

The chemical engineering curriculum contains 39 credit hours of electives. A minimum of 24 of these elective credit hours must be taken in the fields of humanities, social studies, and languages. In addition, 6 credit hours in English are included in required courses, so that each student must take a minimum of 30 credit hours of nontechnical courses. Nine elective hours are considered to be free electives, and courses may be chosen to fit a student's particular needs and objectives. They may be added to the minimum requirements in nontechnical courses, or they may be used to take advanced courses in specialized fields. Students planning to enter graduate schools may use both the free and technical electives to prepare for graduate study. During the sixth term each student must submit a coordinated plan to his adviser indicating the electives he proposes to take and outlining the objectives to be achieved.

OPTIONS

Specialized work is offered in biochemical engineering, petroleum, plastics and rubbers, business administration, nuclear engineering, instrumentation and automation, industrial and engineering administration, and reaction kinetics. The choice of electives at an advanced level allows students to arrange programs that are the equivalent of options in these fields. The exact sequence of courses to be selected for advanced training is not specified, since it depends on the students' interests and capabilities. Exceptional students are allowed to register for graduate courses in these fields.

PREDOCTORAL HONORS PROGRAM

The Predoctoral Honors Program is available to capable undergraduate students who intend to continue their education in graduate schools. It is designed to minimize the time required to obtain a Doctor's degree. If this objective can be achieved, it will aid in increasing the number of students available for teaching, research, and highly technical positions in industry. Two different programs are available to the student. One is oriented towards research and provides actual training in research during the fourth and fifth years. The other puts more

emphasis on design, process evaluation, and the economics of the process industries.

Undergraduates interested in this program must apply for admission during their third year. There are no fixed standards for entry. Students' requests for admission must be approved by the faculty of the School and their progress is reviewed at the end of each term. Approved applicants choose either a research- or design-oriented program as outlined on pages 29–30. Each student is then assigned to a special adviser who must approve the selection of courses to be taken during the fourth and fifth years.

The research-oriented students complete a three-term individual research project and substitute theoretical courses required for doctoral candidates in place of some of the design courses included in the regular curriculum. The design-oriented students may specialize either in engineering design or in the economics of the process industries by appropriate choice of elective courses.

Students enrolled in the honors program who apply for admission to the Graduate School and are accepted may register as graduate students during their fifth year. When they complete the courses included in either of the honors programs listed on pages 29–30, they will be awarded the Bachelor of Chemical Engineering degree. Normally, this requirement can be completed by the end of the fifth year. Students who register in the Graduate School choose a committee that supervises their work. The *Announcement of the Graduate School* should be consulted for details about degree requirements. This program may be terminated at the Master's degree level if a student meets all the requirements.

SCHOLASTIC REQUIREMENTS

A student in the School of Chemical Engineering who does not receive a passing grade in every course for which he is registered, or who fails in any term or summer session to maintain an average of 75, may be dropped or placed on probation.

If, in the opinion of the faculty, a student's general record is unsatisfactory, the student may be refused permission to continue his course even though he has met the minimum requirements of credit hours passed and of grades for those hours. Students who fall behind in their work may be warned, put on probation, or dropped, either from an individual course or from the University, at any time during the term.

CURRICULUM . . . Bachelor of Engineering (Chemical)

Course programs for Term 1 through 4, administered by the Division of Basic Studies, are described on pages 25–26.

		CONTACT HOURS		
		CREDIT HOURS	LECT. REC.	LAB. COMP.
TERM 5	Chemistry 357, Introductory Organic Chemistry	5	3	6
	Enginering 5303, Analysis of Stage Processes	3	2	2
	Engineering 5203, Chemical Processes	2	2	0
	Engineering 211, Mechanics	4	3	2½
	Enginering 5851, Chemical Microscopy	3 or 0	1	5
	Liberal Elective	0 or 4	–	–
	Total	17 or 18		

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 6	Chemistry 358, Introductory Organic Chemistry	5	3	6
	Engineering 5304, Introduction to Rate Processes	3	2	2
	Engineering 5204, Chemical Processes	2	2	0
	Engineering 211, Mechanics	4	3	2½
	Engineering 5851, Chemical Microscopy	0 or 3	1	5
	Liberal Elective	4 or 0	–	–
	Total	18 or 17		
TERM 7	Engineering 5305, Rate Processes and Unit Operations	3	2	2
	Engineering 5103, Chemical Engineering Thermodynamics	3	3	0
	Engineering 5353, Unit Operations Laboratory	3	2	3
	Engineering 5255, Materials	3	3	0
	Liberal Elective	4		
	Total	16		
TERM 8	Engineering 5104, Chemical Engineering Thermodynamics	3	3	0
	Engineering 5354, Project Laboratory	3	1	5
	Engineering 5256, Materials	3	3	0
	Electrical Engineering	3	–	–
	Free Elective	3	–	–
	Liberal Elective	4	–	–
	Total	19		
TERM 9	Engineering 5621, Process Evaluation and Design	5	3	5
	Engineering 5106, Reaction Kinetics	3	3	0
	Chemical Engineering Elective	3	–	–
	Free Elective	3	–	–
	Liberal Elective	4	–	–
	Total	18		
TERM 10	Engineering 5622, Process Evaluation and Design	5	3	5
	Engineering 5717, Process Control	3	2	2½
	Chemical Engineering Elective	3	–	–
	Free Elective	3	–	–
	Liberal Elective	4	–	–
	Total	18		
	Total for ten terms	174		

PREDOCTORAL HONORS PROGRAM

RESEARCH-ORIENTED

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 7	Engineering 5305, Rate Processes and Unit Operations	3	2	2
	Engineering 5103, Chemical Engineering Thermodynamics	3	3	0
	Engineering 5353, Unit Operations Laboratory	3	2	3
	Engineering 5255, Materials	3	3	0
	Engineering 5909, Introduction to Research	0	1	0
	Elective	3	–	–
	Liberal Elective	4	–	–
	Total	19		

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 8	Engineering 5104, Chemical Engineering Thermodynamics	3	3	0
	Engineering 5952, Research Project	3	0	9
	Engineering 5256, Materials	3	3	0
	Electrical Engineering	3	–	–
	Elective	3	–	–
	Liberal Elective	4	–	–
	Total	19		
TERM 9	Engineering 5106, Reaction Kinetics	3	3	0
	Advanced Course Selected From 5100 or 5500 Series	3	3	0
	Engineering 5953, Research Project	3	0	9
	Elective	3	–	–
	Liberal Elective	4	–	–
	Total	16		
TERM 10	Engineering 5954, Research Project	3	0	9
	Advanced Courses Selected From 5100 or 5500 Series	6	6	0
	Elective	3	–	–
	Liberal Elective	4	–	–
	Total	16		
	Total for ten terms	173		

DESIGN-ORIENTED

Terms 7 and 8 are the same as the research-oriented program.

TERM 9	Engineering 5621, Process Evaluation and Design	5	3	5
	Engineering 5106, Recreation Kinetics	3	3	0
	Electives	6	–	–
	Liberal Elective	4	–	–
	Total	18		
TERM 10	Engineering 5622, Process Evaluation and Design	5	3	5
	Engineering 5717, Process Control	3	2	2½
	Electives	6	–	–
	Liberal Elective	4	–	–
	Total	18		
	Total for ten terms	177		

GRADUATE STUDY

REQUIREMENTS FOR THE DEGREE OF MASTER OF ENGINEERING (CHEMICAL)

A candidate must complete a minimum of 54 credits of which 45 must be in technical subjects from the following list (see page 7 for additional information):

Chemistry: Courses in analytical chemistry numbered 426 or higher; in organic chemistry, 456 or higher; in physical chemistry, 380 or higher; in inorganic chemistry, 410 or higher; in biochemistry, 201 or higher.

Physics: Courses numbered 225 or higher.

Mathematics: Courses numbered 200 or higher (except Course 608).

Chemical Engineering: The following courses are approved: 5105, 5107, 5108,

5205–6, 5503–4, 5505–6, 5507, 5508–9, 5605–6–7–8, 5609, 5621–2, 5741–2–3–4–5, 5746, 5747, 5748, 5752, 5760, 5851, 5853, 5859, 5900, 5952–3–4–5–6.

Other branches of engineering: Any course offered in the College of Engineering which is considered by the school or department to be an advanced course.

Of these courses, a minimum of 18 credit hours must be in the basic sciences, including at least 6 credit hours in mathematics and 4 in chemistry.

Also, 18 credit hours must be taken in the chemical engineering courses listed above. Normally, a student will be expected to complete 5503–4 and six hours in a project course.

To complete the degree requirements, all courses in excess of the 45 hours specified are considered electives. They may be technical or nontechnical but must be approved by the student's adviser.

All courses to be counted toward the degree must be passed with a minimum grade of 75 or a signed statement by the professor in charge attesting that the student's work was of graduate caliber.

Graduate study for the Master of Science and Doctor of Philosophy degrees is described in the *Announcement of the Graduate School.*

CIVIL ENGINEERING

HOLLISTER HALL

Civil engineering is concerned primarily with the large fixed works and facilities that are basic to community living, industry, and commerce. In a broad sense, the civil engineer learns to control and modify 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 many 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 must concern himself 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 must 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.

THE CIVIL ENGINEERING CURRICULUM

The new curriculum in civil engineering permits the student considerable freedom in choosing programs and courses that will most nearly suit his particular professional objectives and aptitudes. Subject to the limitations indicated below, 49 credit hours (about 16 courses) out of the 170 hours required for graduation may be elected. Twenty-four of these 49 hours must be devoted to liberal studies and 16 hours must be devoted to subjects directly related to the profession, leaving 9 hours of totally free electives. The remaining 121 hours required for graduation are prescribed and are common for all civil engineering students. Of these, 59 hours are taken in the Division of Basic Studies and 62 hours are included in the civil engineering core. Thus the student is required to develop a strong foundation in mathematics, science, and engineering tech-

nology and to continue his general education. At the same time he will receive instruction in each of the major subfields of the profession and will have the opportunity of concentrating in one area if he so desires.

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 hydraulics laboratories; a highway materials and traffic engineering laboratory; sanitary engineering laboratories; a soils engineering laboratory; and laboratories for interpreting aerial photographs and preparing maps and engineering data by photogrammetric methods.

LIBERAL STUDIES

Students must take 24 credit hours of liberal studies beyond freshman English distributed as evenly as possible throughout the last four years. At least one liberal subject must be taken in six of the last eight terms and, ordinarily, no more than two such courses should be taken in one term. No course will be credited as a liberal study if it has a major technical significance in civil engineering. The subjects must be chosen as follows: 9 hours in humanities (English, fine arts, philosophy, literature, music, classics, speech and drama; with at least one 2-term sequence), 9 hours in social studies (economics [at least 3 hours are required], government, history, psychology, sociology, anthropology; with at least one 2-term sequence), 6 hours either in humanities or social studies or a modern foreign language or a combination thereof, according to a student's preference.

PROFESSIONAL PROGRAMS

The 16 credit hours available for professional programs may be used to further a student's interest in a single area of civil engineering or to broaden his preparation in a number of professionally-related areas. In each case a coherent program of scientific, technical, and/or managerial subjects must be chosen which need not be limited to subjects offered in the School of Civil Engineering. Programs may be oriented to the needs of professional practice or to research and teaching and may, at the option of the student, include some or all of the 9 hours of free electives. The five major areas approved at this time are: (1) structural and soils engineering; (2) water resources engineering, including sanitary engineering and hydraulic engineering; (3) transportation and urban engineering; (4) surveying, construction engineering and administration; and (5) general civil engineering.

Students should indicate the areas they desire to pursue, not later than the 7th term. They will then be assigned advisers who will assist them in planning programs and scheduling courses in accordance with established guidelines.

FREE ELECTIVES

Students are totally free to choose at least nine hours of work in any courses in the University to which they can be admitted. Under this heading, not to exceed 9 hours may be credited toward graduation for courses taken in advanced military, air, or naval science.

SCHOLASTIC REQUIREMENTS

To remain in good standing a student in the School of Civil Engineering must maintain an average grade of at least 70 per cent each term.

GRADUATE HONORS PROGRAM

As indicated on page 4 a limited number of students who meet certain requirements may be admitted to the Graduate School at the end of the fourth year. The subsequent year of in-residence graduate study will then replace the fifth year of the undergraduate curriculum. If, at the end of the fifth year, the student has fulfilled the minimum requirements of the civil engineering curriculum, he will receive the Bachelor of Engineering(Civil) degree; otherwise he will receive a Bachelor's degree in engineering, undesignated as to branch.

To be admitted to the honors program a student must ordinarily be in the top one-quarter of his class and be otherwise clearly qualified for and desirous of pursuing graduate study. He must apply, in writing, for enrollment in this program not later than the 7th term, and be certified by the faculty of the School of Civil Engineering. In order to qualify, he must complete, by the end of the 8th term, 136 credit hours of work, including (in addition to 6 hours of freshman English) at least 18 hours of liberal studies, of which at least 8 hours are in the humanities and 8 hours are in the social studies. He may also be required to perform such additional work as the faculty may prescribe.

CURRICULUM . . . Bachelor of Engineering(Civil)*

		CONTACT HOURS		
		CREDIT HOURS	LECT. REC.	LAB. COMP.
TERM 5	Geology 103, Geology for Engineers	3	2	5
	Engineering 9170, Industrial & Eng. Statistics	3	2	2½
	Engineering 6311L, Material Science I	4	3	2½
	Engineering 2701, Structural Engineering I	3	3	0
	Engineering 2301, Fluid Mechanics	3	3	–
	Liberal Study	3†	–	–
	Total	19		
TERM 6	Engineering 2001, Engineering Materials	3	2	2½
	Engineering 2702, Structural Engineering II	3	2	2½
	Engineering 2302, Hydraulic Engineering	3	2	2½
	Engineering 2101, Surveying	3	2	2½
	Engineering 3633, Thermodynamics	3	3	0
	Liberal Study (or Electrical Science 242 or 244 if not taken in the 4th term)	3	–	–
	Total	18		
TERM 7	Engineering 2703, Structural Engineering III	3	2	2½
	Engineering 2401, Soils Engineering	4	3	2½
	Engineering 2303, Hydrology	2	2	0
	Engineering 2501, Water & Waste Water Treatment	4	3	2½
	Engineering 2102, Surveying	2	1	2½
	Liberal Study	3	–	–
	Total	18		

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 8	Engineering 2704, Structural Engineering IV	3	2	2½
	Engineering 2502, Sanitary Engineering Systems	3	2	2½
	Engineering 2601, Transportation Engineering	4	3	2½
	Professional Selections	0†	–	–
	Liberal Studies	6	–	–
	Total	16		
TERM 9	Engineering 2903, Engineering Economy	3	3	0
	Professional Selections	9†	–	–
	Liberal Study	3†	–	–
	Free Elective	3†	–	–
	Total	18		
TERM 10	Professional Selections	7†	–	–
	Liberal Study	3†	–	–
	Free Electives	6†	–	–
	Total	16		
	Total for ten terms	170		

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

* Applies only to students who enroll in the School of Civil Engineering for the first time in September, 1963, and thereafter. Requirements for other students are available in the School office.

† The above schedule will enable candidates for the Graduate Honors Program to meet requirements by the end of the 8th term. Other students will have some latitude in scheduling professional selections, free electives, and liberal studies especially in the 5th, 8th, 9th, and 10th terms.

GRADUATE STUDY

The School offers work leading to the Master of Engineering(Civil), the professional Master's degree, the M.S., and 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 protographic studies. Descriptions of individual courses are given elsewhere in this Announcement. For information concerning professional Masters' degrees, see page 7.

Prospective graduate students should consult the *Announcement of the Graduate School.* A brochure, *Graduate Programs in Civil Engineering,* is also available upon request from the School of Civil Engineering, Hollister Hall.

ELECTRICAL ENGINEERING

PHILLIPS HALL

The curriculum leading to the degree of Bachelor of Engineering(Electrical) is intended to create in the student an understanding of the meaning and the application of those laws of nature that are basic in the practice of electrical engineering and, at the same time, to provide the opportunity for as much nontechnical course work as is consistent with the primary objective of educating an electrical engineer. Two curricula are described below. The first is that to be in effect for students starting as third-year students in the School of Electrical Engineering in September, 1963, and thereafter. The second is that in effect for those students in the School who expect to graduate by June, 1965. For convenience, the first is described as the new curriculum, and the second as the old curriculum.

THE NEW CURRICULUM

The education of the modern electrical engineer must prepare him for a rapidly expanding field (that includes such recently developed areas as biomedical electronics, thermonuclear and magnetohydrodynamic power generation, space communication and control, computer design, and molecular electronics) and for engineering functions that range from research to production. In revising its 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 have been called *Electrophysics, Systems,* and *Laboratory*. The three themes are interrelated and the revised curriculum contains an integrated series of required courses in each. The conclusion of the faculty concerning the required part of the curriculum has made it possible to limit the number of courses in any one semester to a total of five, the remaining two being elective.

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 new curriculum these subjects are treated in significantly greater depth and breadth than ever before.

The *Systems* sequence is chiefly concerned 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 or active or random. Systems may be used for many purposes, including 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.

The *Laboratory* sequence is to emphasize that new developments in engineering practice come from a blend of theory and experiment. It is a function of the laboratory to bring 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 ability to do experimental work depends upon an understanding of techniques and apparatus and the place to develop this ability is in the laboratory. The new curriculum therefore contemplates an expansion of the time spent by the student in the laboratory. Each of the four laboratory courses involves two laboratory periods per week. There will be sufficient time and flexibility to permit individual exploration, and the eventual goal is to enable the student to devise his own experiments.

ELECTIVE COURSES

The curriculum provides for fourteen elective courses, which must include (a) six courses in the humanities, social studies, or language, of which two are a sequence in humanities and two are a sequence in social studies and (b) four courses in terms 9 and 10 approved as a group by the student's adviser.

It is hoped that students will use their elective courses effectively to pursue their individual interests. The courses have been spread through the three years to allow opportunity to investigate some field of study in depth.

The only limitation on the four-course group in the fifth year is that they be selected to meet some particular career objective. The objective may be to provide greater depth or breadth in electrical engineering, or it may be to prepare for specialized careers by study in such fields as mathematics, physical or life sciences, different fields of engineering, business, law, etc.

SUMMARY CHART OF ELECTRICAL ENGINEERING CURRICULUM

Term	*Systems* *	*Electrophysics* *	*Laboratory* *	*Electives* †
5	4301: Linear Passive Networks (3)	4311: Electromagnetic Waves (4)	4321: El. Lab. I (4)	2 courses (6)
6	4302: Introd. to Active Systems (3)	4312: Applied Thermodynamics (4)	4322: El. Lab. II (4)	2 courses (6)
7	4401: Linear Systems Analysis (4)	4411: Quantum Theory (4)	4421: El. Lab. III (4)	2 courses (6)
8	4402: Active Systems (4)	4412: Solid State Physics (4)	4422: El. Lab. IV (4)	2 courses (6)
9	4501: Systems with Random Signals (4)	4511: Electrodynamics (4)		3 courses (9)
10	4502: Statistical Aspects of System Analysis (4)	4512: Fields, Waves, and Electrons (4)		3 courses (9)

Total Credits: Systems, 22 hours; Electrophysics, 24 hours; Laboratory, 16 hours; Electives, 42 hours.

* Credit hours indicated in parentheses.

† Minimum credit hours indicated in parentheses.

With the adoption of the new curriculum the faculty also provided for a *Pregraduate Honors* program. The Pregraduate Honors program recognizes the fact that some students have the ability and interest to prepare for genuine graduate work in less than the normal time. It differs from the regular curriculum chiefly in the fourth year but to qualify for entrance to the program, a student must successfully complete two courses in applied mathematics, Mathematics 421 and 422, in his third year. For these superior students with their additional mathematics preparation, a different series of courses in the fourth year is provided to prepare for graduate work in the fifth year.

A student in the honors program who is admitted to the Graduate School will spend his fifth year as a graduate student. There will be no additional undergraduate requirements to be satisfied for the Bachelor of Engineering(Electrical) degree. He may pursue his graduate work with exactly the same flexibility of choice as any other graduate student.

SUMMARY CHART FOR PREGRADUATE HONORS CURRICULUM

Term	*Systems* *	*Electrophysics* *	*Laboratory* *	*Mathematics* *	*Electives* †
5	4301: Linear Passive Networks (Spec. Sect.) (3)	4311: Electromagnetic Waves (Spec. Sect.) (4)	4321: El. Lab. I (Spec. Sect.) (4)	421: Applied Math. (4)	1 course (3)
6	4302: Introd. to Active Systems (Spec. Sect.) (3)	4312: Applied Thermodynamics (Spec. Sect.) (4)	4322: El. Lab. II (Spec. Sect.) (4)	422: Applied Math. (4)	1 course (3)
		FORMAL ADMISSION TO PROGRAM			
7	4403: Systems Analysis (Honors) (4)	4411: Quantum Theory (Spec. Sect.) (4)	4421: El. Lab. III (Spec. Sect.) (4)	423: Applied Math. (4)	1 course (3)
8	4404: Prob. Theory and Systems Applications (Honors) (4)	4412: Solid State (Spec. Sect.) (4) 4414: Electro-Physics Honors Seminars (4)	4422: El. Lab. IV (Spec. Sect.) (4)		1 course (3)

Total Credits: Systems, 14 hours; Electrophysics, 20 hours; Laboratory, 16 hours; Mathematics, 12 hours; Electives, 12–16 hours.

* Credit hours indicated in parentheses.

† Minimum credit hours indicated in parentheses.

THE OLD CURRICULUM

The curriculum and elective-course information in effect for those students who expect to graduate by June, 1965, is described in the sections that follow.

CURRICULUM

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 7				
	Engineering 4122, Elements of System Theory	4	3	2½
	Engineering 4221, Alternating Current Machinery	4	2	3
	Engineering 4113, Transmission Lines and Waves	3	2	2½
	Nontechnical Elective	3	–	–
	Free Elective	3		
	Total	17		
TERM 8				
	Physics 314, Atomic, Nuclear, and Solid State Physics	3	3	0
	Engineering 4165, Electromagnetic Theory	4	3	2½
	Engineering 4123, Electronics of Signal Transmission	4	3	2½
	Engineering 4226, Electrical Machinery Laboratory	4	2	3
	Nontechnical Elective	3	–	–
	Total	18		
TERM 9				
	Engineering 4021, Technical Writing and Presentation	3	3	0
	Free Electives	3	–	–
	Nontechnical Elective	3	–	–
	Senior Project 4091 (or Technical Elective)	3	–	–
	Technical Elective	6	–	–
	Nonresident Lectures 4041	1	1	0
	Total	19		
TERM 10				
	Free Elective	6	–	–
	Nontechnical Electives	6	–	–
	Senior Project 4092 (or Technical Elective)	3	–	–
	Technical Electives	3	–	–
	Total	18		
	Total for ten terms	170		

ELECTIVE COURSES

The curriculum in electrical engineering allows each student to choose a considerable number of elective courses during the later years of the curriculum. Of the fifty-one total elective credit hours, twenty-seven must be nontechnical, fifteen must be technical, and nine are completely free. To achieve both breadth and depth in the student's nontechnical program, the twenty-seven nontechnical elective hours must be selected as follows:

1. Nine hours elected from social studies with a two-course sequence included;
2. Nine hours elected from the humanities with a two-course sequence included;
3. Nine hours elected from any nontechnical course.

Fifteen elective credit hours (of which six may be Project) must be selected from courses in electrical engineering, mathematics, or physics. Of these fifteen hours, nine must be taken in electrical engineering. A course so selected must not contain a great amount of material that is essentially equivalent to that in required courses in the curriculum.

The courses, elected in fulfillment of the fifteen-hour technical elective require-

ment, serve as a core for advanced studies in a particular phase of electrical engineering. Students may specialize in radio science, microwave or semiconductor electronics, electric network theory, feedback control systems and computers, nuclear technology, power systems, or applied mathematics and physics. Alternately, some students find it advisable to take advanced courses that lie in more than one of these specialties.

The nine free elective hours may be chosen from among any courses in the University for which prerequisites are satisfied, including those in the foregoing list. By carefully planning the use of electives, students may carry out extensive programs of study in other divisions of the University during the fifth year of the curriculum.

The program of the fifth year includes two three-hour elective courses designated as "Project." A student makes his own selection of the topic or problem that he plans to investigate under the general supervision of a faculty member and prepares a project proposal for submission to his intended project supervisor. In choosing a topic and preparing a proposal, the student is expected to demonstrate the initiative and responsibility he will need to complete the project successfully. It is expected that each student will choose a problem closely related to his major interest in electrical engineering. If his proposal is not approved or if he does not elect to do a project, the student must elect six other technical elective hours.

In many cases students choose to combine all or some portion of the free-elective requirements with the technical-elective requirements in order to emphasize certain studies in electrical engineering. Some of the many fields of studies along with their related courses are listed below. These groupings of courses are not intended to imply that a student must confine his studies to any one field but are presented for general information.

ELECTRIC NETWORK THEORY

4115—Principles of Nonlinear Systems
4563—Signals and Noise in Communications Systems
4564—Transmission of Information
4571—Modern Network Analysis
4572—Modern Network Synthesis
4575—Advanced Topics of System Theory

ELECTRIC POWER SYSTEMS

4351—Unified Theory of Electro-Mechanical Systems
4352—Elements of Power-System Analysis
4353—Transient Analysis of Power Systems

ELECTRONS AND WAVES

4526—Electron Dynamics
4527—Microwave Electronics I
4528—Microwave Electronics II
4521—Microwave Laboratory
4561—Microwave Theory and Techniques
4565—Electromagnetic Theory
4529—Semiconductor Electronics I
4530—Semiconductor Electronics II
4531—Quantum Electronics

FEEDBACK CONTROL SYSTEMS AND COMPUTERS

4711—Feedback Control Systems I
4712—Feedback Control Systems II
4713—Feedback Control Systems Seminar
4810—Analog Computation
4820—Switching Systems I
4821—Switching Systems II
1175—Nonlinear Mechanics

ILLUMINATION

4611—Introductory Illumination
4612—Illumination Engineering
4615—Illumination Seminar
Physics 307—Physical Optics
Psychology 305—Perception

NUCLEAR ENGINEERING

(The following courses constitute the core curriculum for the Engineering College Nuclear Engineering Program.)
8301—Introduction to Atomic Nuclear Physics
or
Physics 314—Atomic, Nuclear and Solid State Physics
8302—Nuclear and Reactor Physics
8351—Nuclear Measurements Laboratory

COMMUNICATION SYSTEMS

4511—Physical Basis of Electronic Engineering
4512—Radio Engineering
4541—Applied Accoustics
4563—Signals and Noise in Communication Systems
4551—Radio Aids to Navigation

RADIO SCIENCE

4565—Electromagnetic Theory
4568—Antennas
4566—Introduction to Plasma Physics
4567—Radio Wave Propagation
4581—Magnetohydrodynamical Processes in the Solar System

Nine credit hours in advanced military science or air or naval science may be counted toward the requirements of the baccalaureate degree. These nine hours are considered to lie within the free-elective area of the curriculum.

GENERAL INFORMATION

CLASS ADVISERS

Each student is assigned an adviser who counsels the student about curriculum, registration, scholarship, and other aspects of the academic program. In addition, the adviser is available to discuss any nonacademic problems the student may have.

Since the class adviser is responsible for approval of the registration of each student, no cancellation of courses or other changes in program may be initiated

without the adviser's approval. If the adviser does not approve a chosen course of study, the student may seek approval of the program by petition to the faculty of the School.

SCHOLASTIC REQUIREMENTS

To remain in good standing, a student must either pass the courses for which he is registered two weeks after the beginning of the term and have a weighted average of not less than 70 per cent; or, if one course is failed or is canceled, have a weighted average for the remaining courses of not less than 75 per cent. A student failing to meet this requirement or failing to make satisfactory progress toward his degree, evidenced either by course failures or by low grades in major courses, may be warned, placed on probation, or dropped from the School.

INDUSTRIAL COOPERATIVE PROGRAM

The School participates in the Industrial Cooperative Program. See page 5 for details.

GRADUATE STUDY

The regulations and requirements for the degrees of Doctor of Philosophy and Master of Science 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 phenomena, magnetohydrodynamics, physical and microwave electronics, material science in electrical engineering, biomedical electronics, electric power conversion, ionized gases in electromagnetic fields, electrical breakdown phenomena, etc., and in the area of systems theory including information theory, network theory, communications systems, feedback control systems, switching circuits, computers, cognitive systems, etc. A number of fellowships, research assistantships, and teaching assistantships are available to candidates for the degree of Doctor of Philosophy and Master of Science 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.

The degree of Master of Engineering (Electrical) is available as a curriculum type of professional degree at the Master's level, the general requirements for which are stated on page 7. Of the forty-five credit hours stated in the general requirements, the degree requires six hours of Project 4091 and 4092, twelve hours of advanced electrical engineering courses (the advanced electrical engineering courses include all the elective and graduate courses listed on pages 93–97 of this Announcement plus 4123, 5165, and 4226), six hours of advanced physics, six hours of advanced mathematics, and fifteen hours from any of the aforementioned groups of electrical engineering, physics, or advanced mathematics courses. All course work to be counted toward the M.Eng. (Electrical) degree requirements must be passed with a minimum grade of 80.

To enter the Master of Engineering(Electrical) program, a student must first have been accepted by the Graduate School for admission as a candidate for the M.S. degree. Upon admission he may petition to the Electrical Engineering Graduate Committee for transfer to the Master of Engineering (Electrical) program. The Master of Engineering(Electrical) program will normally be limited to students who cannot satisfy the residence requirements of the M.S. degree.

ENGINEERING MECHANICS

THURSTON HALL

The Department of Engineering Mechanics is responsible for undergraduate and graduate instruction and research in 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 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 graduate program in applied mechanics and applied mathematics leads to the M.S. and Ph.D. degrees in engineering mechanics. Advanced theoretical and experimental work is basic in the newest developments in engineering and in applied science and provides a foundation for future needs in these fields. The analytical and scientific nature of the studies permits graduates to participate in attacking problems that cut across varied fields of research, development, and design. 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 applied mechanics and applied mathematics find these supporting fields of interest: mathematics, structures, engineering physics, servomechanisms, machine design, aerospace engineering, soil mechanics, and physics.

MATERIALS AND METALLURGY

BARD HALL

Engineering progress depends heavily on the development of new materials and the improvement in the properties of those presently in use. Success of a system, a design, or a theory is realized only when the scheme has been translated by the materials and metallurgical engineer into a tried and tested engine, transistor, or missile. The key is the development, selection, and/or fabrication of the materials. Even a modest improvement of a product is often contingent upon success in materials research, development, and engineering.

The materials and metallurgical engineer must be effectively trained to understand both the behavior and application of materials. The increasing complexity of chemical, mechanical, electrical, and aerodynamic aspects, and their overlap, make it increasingly imperative to understand the basic behavior of the material in the proposed environment or system.

Extensive training in the fundamentals of science and engineering, of materials processing, of materials properties, and of application of materials in design is offered in the materials and metallurgy program, which is conducted by the materials and metallurgy faculty of the Department of Engineering Physics and Materials Science. The facilities include the newest of the Cornell engineering buildings, Bard Hall, the largest of the Materials Science Center laboratories (processing, metallography and X-ray, single crystal, and high temperature), the newest of materials teaching and research facilities, and a balanced faculty oriented toward both producing knowledge by research and applying it through engineering. Four of the seven faculty have substantial engineering experience in nuclear reactor materials, steel and high temperature alloys, materials processing, and space and missile materials. The fields of semiconductor and superconductor materials, glasses and liquids, diffusion and transport, thermodynamics and kinetics are the major areas of interest of the other three professors. The faculty's professional experiences and research interests are the basis of the new materials and metallurgy program which is being offered. The core of the new program includes the following topics: (1) structure of materials, (2) properties and behavior of materials, (3) thermodynamics and kinetics, (4) materials processing, (5) materials engineering and design.

Combining the faculties of materials and metallurgy and of engineering physics under the Department of Engineering Physics and Materials Science provides an integration of physics with materials and metallurgical engineering, as well as exposing the engineering physics students to materials technology, at both the undergraduate and graduate levels.

The number of students enrolled in this program has been traditionally small, fostering individualized learning between student and faculty member. Also, 24 credits of liberal electives plus 21 credits of technical electives included in the

curriculum permit a wide choice of subject areas ranging from law or business administration to polymeric materials (pp. 4, 6, 8). By proper choice of electives it is possible to obtain advanced degrees in a shorter period of time than is normally the case.

The senior project in the final year is selected by the student in his own chosen area of interest. The purpose is to expose the student to those problems associated with a research or development study and provide for the integration of his educational experiences in the solution of his project.

SUGGESTED TECHNICAL ELECTIVE GROUPINGS

MATERIALS SCIENCE

	CREDIT HOURS	TERM
Physics 323, Modified Electricity, Magnetism and Optics	4	7
Physics 318, Modified Analytical Mechanics and Atomic Physics	4	8
Chemistry 481, Advanced Physical Chemistry	4	7
Chemistry 505, Advanced Inorganic Chemistry	4	7
Chemistry 506, Advanced Inorganic Chemistry	4	8
Physics 443, Atomic Physics and Introduction to Quantum Mechanics	4	9
Physics 454, Electronic Properties of Solids and Liquids	4	10
Engineering 6681, Advanced Experimental Metallurgy	3	9
Engineering 6710, Transport Processes	3	10
Engineering 6732, Advanced Metallography	3	10

MATERIALS TECHNOLOGY

Engineering 6661, Metals at Elevated Temperatures	2	9
Engineering 6872, Nuclear Materials Technology	2	10
Engineering 6665, Materials for Space Craft and Missiles	2	9
Engineering 6911, Seminar in Non-Crystalline Materials		
Engineering 3331, Kinematics and Components of Machines	3	7, 8
Engineering 3372, Experimental Methods in Machine Design	3	7, 9

NUCLEAR ENGINEERING

Physics 314, Introduction to Atomic and Nuclear Physics	3	7
Engineering 8302, Nuclear and Reactor Physics	3	8
Engineering 8351, Nuclear Measurements Laboratory	3	8
Engineering 5760, Nuclear and Reactor Engineering	2	9
Engineering 3665, Advanced Heat Transfer	3	9
Engineering 6872, Nuclear Materials Technology	2	10
Engineering 8051, 8052, Project	6	9, 10

POLYMERIC MATERIALS

Chemistry 357, Introductory Organic Chemistry	5	7
Chemistry 358, Introductory Organic Chemistry	5	8
Engineering 5742, Polymeric Materials	3	9
Engineering 5743, Properties of Polymeric Materials	3	10
Engineering 5752, Polymeric Materials Laboratory	2	10

PRODUCTION OPERATIONS AND PROCESS CONTROL (Industrial Engineering)

	CREDIT HOURS	TERM
Engineering 9153, Engineering Economics Analysis	3	7,9
Engineering 9170, Industrial and Engineering Statistics	3	7, 8
Engineering 9381, Introduction to Modern Digital Computation	3	7, 8
Engineering 9570, Intermediate Industrial and Engineering Statistics	3	10
Engineering 9575, Statistical Control	3	8, 10
Engineering 5304, Analysis of Unit Operations	3	8
Engineering 5747, Process Control	3	9

SCHOLASTIC REQUIREMENTS

A student in materials and metallurgy who does not receive a passing grade in every course for which he is registered, or who fails in any term of summer session to maintain an average grade of 70, may be subject to disciplinary action.

CURRICULUM . . . Bachelor of Engineering (Materials and Metallurgy)

Course programs for Terms 1, 2, 3 and 4, administered by the Division of Basic Studies, are described on pages 25–26.

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 5	Engineering 6311, Materials Science	4	3	2½
	Engineering 6301, Structure of Materials I	3	2	2½
	Mathematics 215, Higher Calculus	3	3	0
	Engineering 8121, Classical Thermodynamics	3	3	0
	Liberal Elective	3 or 4		
TERM 6	Physics 314, Atomic, Nuclear and Solid State	3	3	0
	Engineering 6302, Structure of Materials II	3	1	5
	Mathematics 216, Higher Calculus	3	3	0
	Chemistry 353, Organic	4	4	0
	Chemistry 355, Organic	2	0	5
	Liberal Elective	3 or 4		
TERM 7	*Effective in fall, 1964*			
	Engineering 6435, Physical Metallurgy	4	3	2½
	Engineering 6423, Thermodynamics	3	3	0
	Elective (Technical)	6		
	Liberal Elective	3 or 4		
TERM 8	*Effective in spring, 1965*			
	Engineering 6432, Mechanical Metallurgy	3	3	0
	Engineering 6442, Materials Processing (Chemical)	4	3	2½
	Engineering 6443, Materials Processing (Mechanical)	4	3	2½
	Elective (Technical)	3		
	Liberal Elective	3 or 4		
TERM 9	*Effective in fall, 1965*			
	Engineering 6505, Metallurgical Eng. Design *	3		
	Engineering 6553, Senior Project	3	0	9
	Engineering 6539, Principles of Metallurgical Eng.	3	3	0
	Elective (Technical)	3		
	Liberal Elective	3 or 4		

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 10	*Effective in spring, 1966*			
	Engineering 6524, Kinetics of Reactions in Solids	3	3	0
	Engineering 6554, Senior Project	3	0	9
	Elective (Technical)	6		
	Liberal Elective	3 or 4		

* Optional for honors and graduate studies candidates.

RESEARCH AND GRADUATE STUDY

The research program by the staff and students in materials and metallurgical engineering is an integral part of Cornell's interdisciplinary Materials Science Center. Undergraduate students are required to do independent projects in their fifth year, and in this way students have an opportunity to work in areas of advanced research with members of the faculty. Areas in which such work is carried out include liquid-solid interfacial reactions: crystalline imperfections, semiconductors, refractory materials, solidification and crystal growth phenomena, recovery and recrystallization, solid solution strengthening; ordering; transformation kinetics; nuclear materials: X-ray diffraction microscopy, optical and electron microscopy, structure of thin films, and physical and mechanical behavior.

Graduate study programs in materials and metallurgical engineering at Cornell are designed to fit the needs of individual students, in light of their previous training, aptitudes, and interests. Candidates are expected to pursue a program of study that will give them a deeper understanding of the basic and applied sciences, which will develop initiative and originality. A candidate for a general degree, M.S. or Ph.D., is required to take neither a fixed curriculum nor a minimum number of credit hours in his major field. However, the student will ordinarily find it desirable to take advanced courses offered in the Department and to participate in graduate seminars. He will also be urged to pursue advanced courses in mathematics, chemistry, and physics offered in the College of Arts and Sciences. The specific requirements for the M.S. and Ph.D. degrees will be found in the *Announcement of the Graduate School.*

ENGINEERING PHYSICS

ROCKEFELLER HALL

The undergraduate program in engineering physics, conducted by the Department of Engineering Physics and Materials Science, is designed to combine the basic scientific and analytical training of the physicist and the mathematician with knowledge and experience in applying this training to problems in engineering research and engineering development. Accordingly, the curriculum puts major emphasis on mathematics and physics. In addition, the program is planned to develop an appreciation and understanding of the properties of materials from constituent atoms and molecules to bulk physical, electrical, and chemical properties.

For training in engineering research, the fifth year student carries out a semi-research project in his chosen special field under the direction of a faculty member who is an authority in that field. Students may undertake projects in atomic and nuclear physics, nuclear reactor technology, nuclear instrumentation, electron optics and electron microscopy, engineering electronics including communications and servomechanisms, circuit analysis, X-rays and crystal structure, physics of solids, physical metallurgy, radio astronomy and space research, magnetohydrodynamics and aerodynamics, thermodynamics and heat transfer, elasticity and stress analysis, mathematics, and biophysics.

Because of the emphasis on the basic sciences and the freedom to select advanced courses to satisfy electives, the curriculum provides an excellent foundation for graduate study in the sciences or in engineering research.

The Department has fully equipped laboratories for study and research in electron microscopy, solid state and surface physics, and nuclear technology. The Nuclear Reactor Laboratory, a separate building (see page 2), includes facilities for work in nuclear chemistry.

In their project studies students also have access to other engineering laboratories and to those in the College of Arts and Sciences where such laboratories are important to the project.

Including the course work taken in the Division of Basic Studies, the engineering physics undergraduate curriculum requires the student to distribute his total of 165 semester hours of course work as follows:

Mathematics, physics, chemistry, engineering	116 hours
English composition	6 hours
Modern foreign language (for classes of 1963, 1964, 1965) (Students who pass the proficiency examination of the Deparment of Modern Languages and who do not wish to continue the study of a language may substitute six hours of liberal electives in place of the language requirement.)	6 hours
Electives Liberal—18 hours. At least nine hours must be taken in the area of humanities with a 2-term sequence; another nine hours in the area of social studies with a 2-term sequence.	40 hours

Advanced Engineering and Science—12 hours minimum. This includes six hours for Senior Project (see course description 8051).
Unspecified—10 hours. May be taken in any course in the University open to the student. Not more than six hours credit is allowed in advanced military science or in naval science.

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

AEROSPACE ENGINEERING (see p. 17) . . . 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, thermonuclear power principles, advanced heat transfer, and in physics of solids underlying radiation damage problems. His attention is directed to Courses 8302, 8306, 8312, 8351, 8352, and to 3665, 5760, 6872, and 7206, 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), engineering materials (e.g., 1244), and metallurgical engineering (e.g., 6411 and 6412) 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 senior 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 gasdynamics, radio wave propagation, optics, astronomy, relativity, and other related courses. Several faculty members have strong research interests in this field and are available to supervise senior research projects related to their areas of specialization. Students may undertake projects as a part of the work of the Center for Radiophysics and Space Research.

The Department participates in the Industrial Cooperative Program (see page 5).

SCHOLASTIC REQUIREMENTS

The student is urged to regard grades as an indication of his degree of achievement in his field rather than as, in any sense, an end in themselves. The difference of a point or two in grades is never a determining factor in his status in the

Department. He is expected to pass every course for which he is registered, to maintain each term a weighted average of about 75 per cent or better, and to demonstrate aptitude and competence in the basic subject matter of the curriculum.

A student failing to satisfy these requirements may be put on probation or refused permission to continue his studies in the Department.

CURRICULUM . . . Bachelor of Engineering (Physics)

For students who expect to graduate in 1964 and 1965.

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 8	Mathematics 616, Methods of Applied Mathematics	3	3	0
	Physics 454, Electronic Properties of Solids and Liquids	4	4	0
	Physics 410, Advanced Laboratory	4	0	6
	Chemistry 380, Chemical Bonding and Physical Properties of Organic Molecules	3	3	0
	Elective	3	–	–
	Total	17		
TERM 9	Engineering 8252, Selected Topics in Physics of Engineering Materials	3	3	0
	Engineering 8051, Project	3	–	–
	Electives	9	–	–
	Total	15		
Term 10	Engineering 8131, Mechanics of Continua	3	3	0
	Engineering 8052, Project	3	–	–
	Electives	9	–	–
	Total	15		

For students who entered in 1961 and thereafter, course programs for Terms 1 through 4, administered by the Division of Basic Studies, are described on pages 25–26.

TERM 5	Mathematics 421, Methods of Applied Mathematics	4	4	0
	Physics 323, Modified. Electricity and Magnetism and Optics	4	4	0
	Engineering 8121, Thermodynamics and Kinetic Theory	3	3	0
	Engineering 6311, Materials Science	4	3	2½
	Elective	3 or 4		
	Total	18		
TERM 6	Mathematics 422, Methods of Applied Mathematics	4	4	0
	Physics 318 Modified, Analytical Mechanics and Atomic Physics	5	5	0
	Engineering 8122, Thermodynamics and Kinetic Theory	3	3	0
	Modern Foreign Language	6	2	6
	Total	18		

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 7	Mathematics 423, Methods of Mathematics	4	4	0
	Physics 443, Atomic and Molecular Physics	4	4	0
	Engineering 4301, Linear Passive Networks	3	2	1
	Engineering 4321, Electrical Engineering Laboratory	4	1	5
	Elective	3 or 4		
	Total	18		
TERM 8	Physics *	4		
	Physics 410, Advanced Laboratory	4	0	6
	Engineering 4302, Introduction to Active Systems	3	2	1
	Chemistry 380, Chemical Bonding and Physical Properties of Organic Molecules	3	3	0
	Elective	3 or 4		
	Total	17		
TERM 9	Engineering 8252, Selected Topics in Physics of Engineering Materials	3	3	0
	Engineering 8051, Project	3	–	–
	Electives	8		
	Total	14		
TERM 10	Engineering 8131, Mechanics of Continua	3	3	0
	Engineering 8052, Project	3	–	–
	Electives	8	–	–
	Total	14		
	Minimum Credit Hours	102		

* Either Physics 454 or 444, or Engineering 8302.

GRADUATE STUDY

The objective of graduate instruction in engineering physics is to offer concentrated study in a field which crosses conventional subject matter boundaries as well as to deepen and enlarge both the general scientific and the engineering background of the student.

Though engineering physics undergraduate work is the preferred preparation for graduate work in engineering physics, qualified students with a conventional physics or with another engineering background may enroll for graduate work.

The Graduate School imposes few requirements, permits great latitude to the individual in choice of studies, and expects each candidate to utilize all the resources of the University relevant to his work. It encourages him to associate freely with scholars who will give him the aid and direction he needs to develop a sense of responsibility for the wise application of knowledge.

Accordingly there are no specific course requirements or curricula for graduate study in engineering physics. Each student's program, both formal course work and independent individual study, is adjusted to fit his needs and to provide him with a thorough knowledge of a special field and with adequate peripheral competence. General information and regulations are given in the *Announcement of the Graduate School.* A descriptive brochure can be obtained by writing directly to the Office of the Department of Engineering Physics and Materials Science, Rockefeller Hall.

INDUSTRIAL ENGINEERING

UPSON HALL

Industrial engineering * involves the analysis and design of integrated systems of men, materials, and equipment to perform a useful economic function. Examples of systems which are of interest to industrial engineers include systems to manufacture a given product, including the decision rules to control the operation of the enterprise and its equipment; integrated communication-information processing systems to control and direct the activities of a complex organization; and distribution systems that control the location, quantity, and movement of various inventories to serve an uncertain demand or to regulate inventories from a variable supply. While prior to 1950 nearly all industrial engineering work took place in the mechanical manufacturing industries, today this work is almost equally commonplace in the process industries and is found in service industries, government, and institutional operations as well as manufacturing. The scope of the work has tended to outgrow the designation as industrial engineering, and this type of activity also is often identified as operations research, operations analysis, management science, systems analysis, or systems engineering.

Following the first two years' work in the Division of Basic Studies, the curriculum leading to the Bachelor's degree in industrial engineering develops the necessary background in probability theory, modern algebra, statistics, computing, and cost analysis. Then an integrated sequence of courses develops various analytical techniques and a design methodology appropriate for such systems. The required courses, coupled with a well planned elective program, allows the student an opportunity to develop a course of study of considerable breadth or depth to suit his own needs.

CLASS ADVISERS

Each class will be assigned an adviser who serves in this capacity until the class graduates. In addition to counseling each student about curriculum, possible elective sequences to achieve particular objectives, registration, scholarship, and other aspects of the academic program, the adviser is available to discuss any nonacademic problems the students may have and to refer them to other offices if such action appears to be in the best interest of the student.

Inasmuch as the class adviser is responsible for approval of the registration of each student, no cancellation of courses or other changes in program may be initiated without his knowledge and approval.

* Although some work in industrial engineering has been offered at Cornell since 1904, this work has heretofore been located within the Sibley School of Mechanical Engineering, and students have received a mechanical engineering degree. The program and curriculum described are to be made available to students who matriculate at Cornell in 1961 or later, subject to final approval by the University faculty and the Board of Trustees. This program has been approved by the faculty of the College of Engineering, and the final approvals required are expected to be given during the 1963–1964 academic year.

SCHOLASTIC REQUIREMENTS

A student in the Department of Industrial Engineering and Administration 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 70, or who is not otherwise making substantial and steady progress toward the completion of his degree requirements, may be dropped or placed on probation.

CURRICULUM . . . Bachelor of Engineering (Industrial)

Course programs for Terms 1, 2, 3, and 4, administered by the Division of Basic Studies, are described on pages 25–26. The curriculum which follows is available to students matriculating in September, 1961, or thereafter, subject to final approval by the Board of Trustees of Cornell University. (See footnote at bottom of page 53.)

		CONTACT HOURS		
		CREDIT HOURS	LECT. REC.	LAB. COMP.
TERM 5	Engineering 9360, Introduction to Probability Theory	3	3	0
	Engineering 9381, Introduction to Digital Computation	3	2	2½
	Engineering 4301, Linear Passive Networks	3	2	2½
	Engineering 6311, Materials Science I	3	3	0
	Engineering 3431, Materials Processing	3	1	5
	Elective *	3	–	–
	Total	18		
TERM 6	Engineering 9370, Introduction to Statistical Theory with Engineering Applications	4	3	2½
	Engineering 9350, Principles of Costing & Control	3	2	2½
	Engineering 4302, Introduction to Active Systems	3	2	2½
	Engineering 6312, Materials Science II	3	3	0
	Engineering 3331, Kinematics and Components of Machines	3	2	2½
	Electives *	3	–	–
	Total	19		
TERM 7	Engineering 9310, Industrial Engineering: Analysis and Design I	4	2	5
	Engineering 9351, Cost Analysis	3	2	2½
	Engineering 3332, Mechanical Systems	3	2	2½
	Engineering 3630, Thermodynamics	3	3	0
	Electives *	3	–	–
	Total	16		
TERM 8	Engineering 9320, Analytical Methods in Industrial Engineering	4	3	2½
	Engineering 3631, Fluid Mechanics	3	3	0
	Engineering Elective	3	–	–
	Electives *	9	–	–
	Total	19		

* The elective courses marked with an asterisk must include twenty-one credit hours of liberal courses, while nine credit hours can be unspecified. (See Liberal Studies in Engineering, p. 4.)

		CREDIT HOURS	CONTACT HOURS LECT. REC.	LAB. COMP.
TERM 9	Engineering 9311, Industrial Engineering Analysis and Design II	4	3	2½
	Engineering 3632, Heat Transfer	3	3	–
	Engineering 9398, Industrial Engineering Project	3	–	–
	Engineering Elective	3	–	–
	Electives *	6	–	–
	Total	19		
TERM 10	Engineering 9352, Industrial and Engineering Administration	3	3	0
	Engineering 9399, Industrial Engineering Project	3	–	–
	Engineering Electives	6	–	–
	Electives *	6	–	–
	Total	18		

ELECTIVE COURSES

The curriculum in industrial engineering includes forty-two elective hours in addition to those in the basic two-year program. Of these, twenty-one must be in liberal courses, twelve in engineering, and nine are completely free. The curriculum is designed in such a way that the student has a chance to use the elective hours to maximum advantage in meeting his particular objectives. For example, a student desiring to combine the basic program in industrial engineering with work in some phase of electrical engineering would find that he could take as many as six three-hour courses in electrical engineering, in addition to the four required courses in this field. Similarly he could work out strong programs in some area of mechanical engineering, such as machine design, to supplement the required work in this field, in various areas of civil engineering, such as sanitation or transportation, or in almost any technical engineering area. On the other hand, a student interested in developing a program in some depth in a nontechnical area could combine as many as twelve hours of his liberal electives with the nine free electives and set up a program of as many as twenty-one hours in one of such fields as sociology, psychology, economics, history, or government. A third choice would be to concentrate the technical electives in more basic work in mathematical and statistical analysis in order to prepare for graduate work in the field of industrial engineering and operations research. In any event, a minimum of nine hours of social studies, including a two-course sequence, and nine hours of humanities, including a two-course sequence are required. Students who contemplate graduate study are advised to take an appropriate language. The elective program selected by the student must receive the approval of his adviser.

Samples of the many possible elective programs are:

INFORMATION PROCESSING

9580—Digital Systems Simulation
9581—Integrated Information Processing Systems
9584—Structure of Computing Languages
9585—Complex Information Processes
Math 325—Numerical Analysis

OPERATIONS RESEARCH

9520—Mathematical Programming
9523—Operations Research II
9524—Problems in Operations Research
9570—Intermediate Industrial and Engineering Statistics
9580—Digital Systems Simulation

ELECTRICAL SYSTEMS ENGINEERING

4401—Linear Systems Analysis
4402—Active Systems
4501—Systems with Random Signals
9560—Applied Stochastic Processes I
9585—Complex Information Processes

MANAGEMENT SCIENCE

9520—Mathematical Programming
9525—Flow and Scheduling in Networks
9562—Inventory Theory
9572—Statistical Decision Theory
9580—Digital Systems Simulation

MANUFACTURING ENGINEERING

9510—Work Design and Measurement
9511—Manufacturing Engineering
9512—Statistical Methods in Quality and Reliability Control
9521—Production Planning and Control
9580—Digital Systems Simulation

APPLIED INDUSTRIAL STATISTICS

9560—Applied Stochastic Processes
9561—Queuing Theory
9570—Intermediate Industrial Statistics
9571—Design of Experiments
9572—Statistical Decision Theory

DUAL REGISTRATION IN THE GRADUATE SCHOOL OF BUSINESS AND PUBLIC ADMINISTRATION

Industrial Engineering students may find attractive the possibility of dual registration in the Graduate School of Business and Public Administration. Qualified students who elect as their field of concentration in that school the area of quantitative analysis will find that by proper selection of electives in the fifth year, the requirements for the M.B.A. degree may be fulfilled in one additional year. The suggested elective program is:

9528—Operations Research II
9581—Integrated Information Processing Systems
BPA 100—Introduction to Administration
BPA 102—The American Economy
BPA 104—Finance
BPA 106—Marketing

THE GRADUATE HONORS PROGRAM

Qualified students in industrial engineering may be admitted to the Graduate School at the end of the fourth year and spend the fifth year as regular graduate students. Such students will be awarded a Bachelor of Engineering degree at the end of the fifth year in addition to any graduate degree or credit toward a graduate degree earned provided they are in good standing at the time. Students interested in this program should discuss it with their advisers prior to registering for the fourth year.

GRADUATE STUDY

Two different types of graduate programs are offered in industrial engineering. The Master of Science and Doctor of Philosophy programs are designed for those primarily interested in teaching or in academic or industrial research. The professional Master of Industrial Engineering degree program is designed for those primarily interested in becoming more proficient in the practice of modern industrial engineering. A student matriculating for one of these graduate degrees may concentrate his studies in any one of several subjects such as industrial engineering, operations research, systems analysis and design, applied statistics and probability, engineering administration, and information processing.

To be accepted as a candidate for the Master of Science or Doctor of Philosophy degrees 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 commendable undergraduate scholastic record and other evidence of his interest in and ability to pursue advanced study and research in the selected field. To be accepted as a candidate for the Master of Industrial 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 the chosen subject of specialization, and (3) show promise of doing well in advanced study as judged by his previous scholastic record or other achievements.

For further information about each of these graduate programs see the earlier references to graduate study on page 6 of this Announcement, the *Announcement of the Graduate School,* and a brochure entitled *Graduate Work in Operations Research, Industrial Engineering, Applied Statistics, and Related Areas,* which may be obtained by writing the Department of Industrial Engineering and Administration, Upson Hall.

MECHANICAL ENGINEERING

UPSON HALL

Mechanical engineers design and develop diverse systems for power generation, machinery for industrial and private consumption, and enterprises for manufacturing and production.

The Sibley School of Mechanical Engineering consists of four departments of instruction:

Graphics and Industrial Design, T. J. Baird, 408 Upson Hall.
Machine Design, A. H. Burr, 306 Upson Hall.
Materials Processing, J. R. Moynihan, 220 Kimball Hall.
Thermal Engineering, D. G. Shepherd, 206 Upson Hall.

Extensive, modern laboratories in each of these departments provide the student with the finest equipment for studying engineering principles. The mechanical engineering laboratories and classrooms are located in Upson Hall. All materials processing laboratories are in Kimball Hall.

BACHELOR OF ENGINEERING (MECHANICAL) PROGRAM FOR CANDIDATES IN 1966 AND THEREAFTER

Students who entered the College of Engineering at the freshman level in September, 1961, or later, are enrolled in the Division of Basic Studies for their freshman and sophomore years (see p. 24). Those who elect to enter the Sibley School of Mechanical Engineering as candidates for the B.Eng. (Mech.) degree may do so at the start of their junior year and will follow a six-term sequence of courses described in the two following sections.

REQUIREMENTS FOR THE BACHELOR OF ENGINEERING (MECHANICAL) DEGREE BY SUBJECTS FOR CANDIDATES IN 1966 AND THEREAFTER

All candidates for the B.Eng.(Mech.) degree after June, 1965, must satisfy certain course requirements in the Departments of Thermal Engineering, Machine Design, and Materials Processing in the Sibley School of Mechanical Engineering. In addition, they must take specified courses in the Division of Basic Studies, in the School of Electrical Engineering, and in the Departments of Industrial Engineering, and Engineering Physics and Materials Science. This work accounts for eighty-five of the 175 hours required for the degree and constitutes a core of courses offered in the College of Engineering throughout five years.

All candidates must also take specified courses in mathematics, physics, and chemistry. These total thirty-six of the 175 hours required for the degree and appear in the Basic Studies program during the freshman and sophomore years.

The remaining fifty-four hours required for the B.Eng.(Mech.) degree include six hours of English and forty-eight hours of electives distributed over all ten terms.

A breakdown of the requirements in these three categories—engineering, science, and English plus electives—appears in the following outline:

ENGINEERING COURSES	CREDITS	
Problems and Methods	6	
Engineering Mechanics	8	
Electrical Science	6	
Materials Science	6	
Thermal Science and Thermal Engineering	21	
Machine Design	16	
Materials Processing	6	
Industrial Engineering and Administration	10	
Electrical Engineering	6	
		85
SCIENCE COURSES		
Mathematics	15	
Physics	12	
Chemistry	9	
		36
ENGLISH AND ELECTIVES		
English	6	
Liberal Electives	24	
Engineering Electives including Project	15	
Unrestricted Electives	9	
		54
Total		175

BACHELOR OF ENGINEERING (MECHANICAL) CURRICULUM FOR CANDIDATES IN 1966 AND THEREAFTER

TERMS 1–4 *See* Division of Basic Studies Curriculum, pages 25–26.

TERM 5 Offered fall, 1963	CREDIT HOURS	LECT. REC.	LAB. COMP.
Engineering 3241, Industrial and Engineering Statistics	3	2	2½
Engineering 3321, Kinematics and Dynamics of Mechanisms	4	3	2½
Engineering 3621, Thermal Science I	3	3	0
Engineering 4301, Electrical Engineering I	3	2	2½
Engineering 6311, Materials Science I	3	3	0
Liberal elective	3, 4		
Total	19, 20		
TERM 6 Offered spring, 1964			
Engineering 3421, Processing of Materials I	3	2	2½
Engineering 3622, Thermal Science II	3	3	0
Engineering 3623, Thermal Science III	3	3	0
Engineering 4302, Electrical Engineering II	3	2	2½
Engineering 6312, Materials Science II	3	2	2½
Liberal elective	3, 4		
Total	18, 19		

	CREDIT HOURS	LECT. REC.	LAB. COMP.
TERM 7 Not offered until fall, 1964			
Engineering 3322, Mechanical Analysis and Design	5	3	5
Engineering 3422, Processing of Materials II	3	1	5
Engineering 3624, Thermal Science IV	3	2	2½
Engineering 3625, Thermal Science V	4	3	2½
Liberal elective	3, 4		
Total	18, 19		
TERM 8 Not offered until spring, 1965			
Engineering 3323, Design of Machines	3	1	5
Engineering 3324, Vibration and Control of Mechanical Systems	4	3	2½
Engineering 3626, Thermal Systems Engineering	5	3	2½
Engineering elective	3		
Liberal elective	3, 4		
Total	18, 19		
TERM 9 Not offered until fall, 1965			
Engineering 9153, Engineering Economic Analysis	3	2	2½
Mechanical engineering project	3		
Mechanical engineering elective	3		
Unrestricted electives	6		
Liberal elective	3, 4		
Total	18, 19		
TERM 10 Not offered until spring, 1966			
Engineering 9110, Introduction to Industrial Engineering	4	3	2½
Mechanical engineering project	3		
Engineering elective	3		
Unrestricted elective	3		
Liberal electives	6, 8		
Total	19, 21		
Minimum total for ten terms	175		

INDUSTRIAL COOPERATIVE PROGRAM

See page 5.

GRADUATE STUDY

Specialized programs for a Master's degree, M.Eng. (Mech.), in the area of machine design are available in the fields of machine dynamics and control, mechanical analysis and development, mechanical design, and vehicles and propulsion; in the area of thermal engineering, in heat transfer and fluid dynamics, nuclear technology, propulsion engines, thermal environment, and thermal power.

For further information about the programs for the professional Masters' degrees, see page 7 of this Announcement; for additional information on the Master of Science (M.S.) and the Ph.D. degrees, see page 6. For each of these graduate programs see also the *Announcement of the Graduate School* and the brochure, *Graduate Programs in Mechanical Engineering*, which may be obtained by writing to the School of Mechanical Engineering, Upson Hall.

REQUIREMENTS FOR THE DEGREE OF BACHELOR OF ENGINEERING (MECHANICAL), BY SUBJECTS, FOR 1964, 1965 CANDIDATES

All mechanical engineering students must satisfy course requirements in each of the four departments of the School, and, in addition, must take specified courses in the School of Electrical Engineering, and in the Departments of Engineering Mechanics, Industrial Engineering and Administration, and Engineering Physics and Materials Science. This work accounts for ninety-nine of the 180 credit hours required for the degree and constitutes a basic group of courses offered in the College of Engineering throughout five years.

All mechanical engineering students must take specified courses in mathematics, physics, chemistry, English, and speech. These courses total forty-one of the 180 credit hours required for graduation.

The remaining forty hours of elective courses required for the degree of Bachelor of Engineering (Mechanical) are described in the following outline, which summarizes the degree requirements.

ENGINEERING COURSES OFFERED IN:	CREDITS	
Orientation; nonresident lectures	4	
Engineering Drawing	6	
Industrial Engineering and Administration	17	
Machine Design	12	
Materials Processing	5	
Thermal Engineering	21	
Electrical Engineering	9	
Chemical Engineering and Metallurgical Engineering	4	
Engineering Mechanics and Engineering Materials	21	
		99
SCIENCES, ENGLISH, SPEECH:		
Mathematics	12	
Physics	12	
Chemistry	8	
English	6	
Public Speaking	3	
		41
ELECTIVES:		
Liberal Arts *	12	
Engineering (including Project, 6 hours) †	14	
Unrestricted ‡	14	
		40
Total		180

* May be chosen from the fields of American studies, the classics, economics, English, fine arts, government, history, literature, modern languages, music, philosophy, psychology, sociology, anthropology, and speech and drama. Courses in these fields are available in several colleges of the University and are not limited to the offerings of any single division.

† Includes all courses offered by the College of Engineering which are not the equivalent of any courses specifically required in the mechanical engineering curriculum.

‡ May be chosen from both of the groups mentioned above or from any division of the University, including 6 hours of advanced ROTC or 9 hours of Naval ROTC. These electives may be used to take more course work in mathematics, physics, and chemistry.

BACHELOR OF ENGINEERING (MECHANICAL) PROGRAMS FOR 1964, 1965 CANDIDATES

Candidates for the Bachelor of Engineering(Mechanical) degree in June of 1964 and 1965 are expected to fulfill the requirements for that degree according to the curriculum they have been following since their freshman year. The first six terms of this ten-term sequence have been completed and do not appear in this Announcement. The last four terms are:

		CONTACT HOURS		
		CREDIT	LECT.	LAB.
TERM 7		HOURS	REC.	COMP.
	Engineering 3604, Flow Processes and Energy Transfer	3	2	2½
	Engineering 3605, Heat Transfer	3	2	2½
	Engineering 3353, Design of Machine Members	3	2	2½
	Engineering 1243, Engineering Materials Laboratory	3	2	2½
	Engineering 3263, Production Engineering	3	2	2½
	Electives	3		
	Total	18		
TERM 8				
	Engineering 3354, Design of Machines	3	1	5
	Engineering 4931, Electrical Engineering	3	2	2½
	Engineering 3264, Production Engineering	3	2	2½
	Engineering 3606, Thermal Engineering Laboratory	3	1	2½
	Engineering 6112, Metallurgy of Casting, Working, and Welding	2	2	0
	Electives (including Engineering 3607, 3608, or 3609)	6		
	Total	20		
TERM 9				
	Project	3		
	Engineering 4932, Electrical Engineering	3	2	2½
	Engineering 1154, Strength of Materials	3	3	0
	Electives	10		
	Total	19		
TERM 10				
	Project	3		
	Engineering 4933, Electrical Engineering	3	2	2½
	Public Speaking 201	3	3	0
	Engineering 3041, Nonresident Lectures	1	1	0
	Electives	9		
	Total	19		
	Total for ten terms	180		

ELECTIVE REQUIREMENTS FOR 1964, 1965 CANDIDATES

The five-year curriculum allows time for forty hours of elective work, including six hours of project.

The elective requirements suggest possibilities that will satisfy a variety of personal desires and interests. It is possible to obtain:

1. Twelve to twenty-six credit hours in liberal arts—all in one area or divided

among several areas. This, together with the nine required hours of English and speech, makes possible a total of thirty-five hours in liberal arts.

2. Fourteen to twenty-eight hours in an engineering option to provide concentration and depth in one particular area of engineering; or these hours may be divided among two or more areas. Those students who contemplate graduate study leading to the degrees of Master of Engineering (Mechanical), Master of Engineering(Industrial), Master of Science, or Master of Engineering (Aerospace) should give serious consideration to the courses they elect. Some courses are acceptable as credit toward both the Bachelor of Engineering(Mechanical) degree and the professional Masters' degrees.
3. Up to fourteen hours of unrestricted elective credit in any special program of studies which is neither liberal arts nor engineering. This includes advanced ROTC.

Students seeking maximum depth of training in any particular field—whether it be in liberal arts, in engineering, or in some other general area—should study the Announcements of the colleges offering the work and consult with representatives of the particular faculties concerned, as well as with their engineering advisers.

To illustrate what can be accomplished in setting up substantial elective options in engineering, the following samples are presented.

GRAPHICS AND INDUSTRIAL DESIGN

INDUSTRIAL DESIGN

	CREDIT HOURS	TERM
Engineering 3116, Introduction to Industrial Design	3	8
Engineering 3198, 3199, Project	6	9, 10
Electives from the following list:	15	5–10
Architecture 330, 331, Sculpture		
400, 401, History of Architecture		
Fine Arts 101, 102, Introduction to Art: Painting and Sculpture		
or		
104 Introduction to Art		
111, 112 Introduction to Art: Architecture		
554 Twentieth-Century Painting		
Home Economics H.D. 100, Color and Design		
Total	24	

ENGINEERING DESIGN

MECHANICAL DESIGN (SYNTHESIS)

	CREDIT HOURS	TERM
Engineering 3366, Advanced Kinematics	3	8
Engineering 3367, Design Problems in Vibrations and Dynamics	3	8
Engineering 3374, Creative Design	3	9
Engineering 3375, Automatic Machinery	3	9
Engineering 3380, Design of Complex Systems	3	10
Engineering 3398, 3399, Design Projects	6	9, 10
Total	21	

DESIGN DEVELOPMENT (ANALYSIS AND EXPERIMENTATION)

	CREDIT HOURS	TERM
Engineering 3361, Advanced Machine Analysis	3	9
Engineering 3362, Mechanical Design of Turbomachinery	3	10
Engineering 3367, Design Problems in Vibrations and Dynamics	3	8
Engineering 3372, Experimental Methods in Machine Design	3	9
Engineering 3376, Automatic Control	3	10
Engineering 3398, 3399, Analysis or Experimental Projects	6	9, 10
Total	21	

VEHICLES AND PROPULSION

Engineering 3367, Design Problems in Vibrations and Dynamics	3	8
Engineering 3377, Automotive Engineering	3	9
Engineering 3374, Creative Design or Engineering 3380, Design of Complex Systems	3	9, 10
Engineering 3398, 3399, Vehicle Design Project	6	9, 10
Engineering 3607, Combustion Engines	3	8
Total	18	

THERMAL ENGINEERING

FLUID DYNAMICS AND HEAT TRANSFER

Engineering 3661, Advanced Thermodynamics	3	7
Engineering 3663, Advanced Turbomachinery	3	9
Engineering 3664, Advanced Fluid Mechanics	3	8
Engineering 3665, Advanced Heat Transfer	3	9
Engineering 3698, 3699, Project	3	9, 10
Total	18	

NUCLEAR ENGINEERING

Engineering 3608, Thermal Power Plants	3	8
Engineering 3665, Advanced Heat Transfer	3	9
Engineering 3698, 3699, Project	6	9, 10
Engineering 8301, Atomic and Nuclear Physics	3	9
Engineering 8311, Nuclear and Reactor Physics	3	10
Engineering 8351, Nuclear Measurements Laboratory	3	10
Total	21	

PROPULSION ENGINES

Engineering 3607, Combustion Engines	3	8
Engineering 3661, Advanced Thermodynamics	3	7
Engineering 3663, Advanced Turbomachinery	3	9
Engineering 3665, Advanced Heat Transfer	3	9
Engineering 3671, Aerospace Propulsion Systems	3	9
Engineering 3698, 3699, Project	6	9, 10
Total	21	

THERMAL ENVIRONMENT

	CREDIT HOURS	TERM
Engineering 3609, Refrigeration and Air Conditioning	3	8
Engineering 3665, Advanced Heat Transfer	3	9
Engineering 3666, Advanced Air Conditioning	3	9
Engineering 3667, Temperature Measuring Instruments	3	8
Engineering 3698, 3699, Project	6	9, 10
Engineering 4934, Principles of Automatic Control	3	10
Total	21	

THERMAL POWER

Engineering 3361, Advanced Thermodynamics	3	7
Engineering 3607, Combustion Engines	3	8
Engineering 3608, Thermal Power Plants	3	8
Engineering 3670, Advanced Combustion Engines	3	10
Engineering 3672, Energy Conversion	3	10
Engineering 3698, 3699, Project	6	9, 10
Total	21	

AEROSPACE ENGINEERING

Mathematics 1180, Mathematical Methods in Engineering I	3	5
Mathematics 1181, Mathematical Methods in Engineering II	3	6
Engineering 1170, Advanced Dynamics	3	7
Engineering 7101, Fundamentals of Aerodynamics	3	7
Engineering 7102, Fundamentals of Astronautics	3	8
Engineering 7203, Gasdynamics I	3	9
Engineering 7204, Gasdynamics II	3	10
Engineering 7801, Project	3	9, 10
Total	24	

ENGINEERING MECHANICS AND MATERIALS

MECHANICS

Engineering 1154, Advanced Strength of Materials	3	7
Engineering 1159, Advanced Mechanics Laboratory	3	10
Engineering 1162, Mechanics of Vibration	3	8
Engineering 1163, Applied Elasticity	3	9
Engineering 1180, Mathematical Methods	3	9
Engineering 1198, 1199, Project	6	9, 10
	27	

MATERIALS TECHNOLOGY

Engineering 3367, Design Problems in Vibrations and Dynamics	3	8
Engineering 3372, Experimental Methods in Machine Design	3	9
Engineering 4711, Feedback Control Systems I	3	9
Engineering 6353, Introductory Metallography	3	8
Engineering 6415, Principles of Materials Processing	3	9
Engineering 6661, Metals at Elevated Temperatures	2	9
Engineering 6872, Nuclear Materials Technology	2	10
Project, Machine Design or Metallurgical Engineering	6	9, 10
Total	19	

NUCLEAR ENGINEERING

	CREDIT HOURS	TERM
Engineering 3665, Advanced Heat Transfer	3	9
Engineering 5760, Nuclear and Reactor Engineering	2	9
Engineering 6872, Nuclear Materials Technology	3	10
Engineering 8051, 8052, Project	6	9, 10
Engineering 8301, Introduction to Atomic and Nuclear Physics	3	7
Engineering 8311, Nuclear and Reactor Physics	3	8
Engineering 8351, Nuclear Measurements Laboratory	3	8
Total	23	

INDUSTRIAL ENGINEERING

MANUFACTURING ENGINEERING

Engineering 3298, 3299, Project	6	9, 10
Engineering 9181, Introduction To Modern Digital Computation	3	8
Engineering 9360, Introduction To Probability Theory With Engineering Applications	3	7
Engineering 9370, Introduction to Statistical Theory With Engineering Applications	4	8
Engineering 9511, Manufacturing Engineering	3	9
Engineering 9521, Production Planning	3	10
Engineering 9580, Digital Systems Simulation	3	10
Total	25	

PRODUCTION MANAGEMENT

Engineering 3298, 3299, Project	6	9, 10
Engineering 9181, Introduction to Modern Digital Computation	3	9, 10
Engineering 9370, Introduction to Statistical Theory With Engineering Applications	4	8
Engineering 9521, Production Planning	3	8
Engineering 9522, Introduction to Operations Research	3	7
Engineering 9554, Analytics of Decision and Control	3	9
Total	22	

SYSTEMS ENGINEERING

Engineering 3298, 3299, Project	6	9, 10
Engineering 9181, Introduction To Modern Digital Computation	3	8
Engineering 9360, Introduction To Probability Theory With Engineering Applications	3	7
Engineering 9521, Production Planning	3	10
Engineering 9522, Introduction To Operations Research	3	7
Engineering 9554, Analytics of Decision and Control	3	9
Engineering 9570, Intermediate Industrial And Engineering Statistics	3	8
Engineering 9580, Digital Systems Simulation	3	10
Total	27	

APPLIED INDUSTRIAL STATISTICS

	CREDIT HOURS	TERM
Engineering 3298, 3299, Project	6	9, 10
Engineering 9181, Introduction To Modern Digital Computation	3	10
Engineering 9360, Introduction To Probability Theory With Engineering Applications	3	7
Engineering 9370, Introduction To Statistical Theory With Engineering Applications	4	8
Engineering 9520, Mathematical Programming or Engineering 9561, Queuing Theory	3	10
Engineering 9570, Intermediate Industrial And Engineering Statistics	3	8
Engineering 9571, Advanced Industrial And Engineering Statistics	3	9
Engineering 9573, Statistical Aspects Of Reliability	3	9
Total	28	

Some of the elective courses appearing in these suggested options may, under certain conditions, be used to satisfy requirements for both the undergraduate and the graduate degrees. Other electives, including advanced mathematics courses, particularly, are also essential for graduate work. Prospective graduate students should seek guidance from members of the graduate staff in arranging their elective programs.

SCHOLASTIC REQUIREMENTS

A student in the School of Mechanical Engineering who fails in any term to earn a passing grade in fifteen hours, with a grade of 70 or better in eleven hours, may be placed on probation. If he fails in any term to pass twelve hours, he may be dropped from the School.

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 or college in which they are offered. Courses in chemistry, English, mathematics, physics, and certain courses in economics are offered by the College of Arts and Sciences.

Courses offered by the Division of Basic Studies in the College of Engineering have three digit numbers. 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. Engineering Mechanics
2. Civil Engineering
3. Mechanical Engineering
4. Electrical Engineering
5. Chemical Engineering
6. Materials and Metallurgical Engineering
7. Aerospace Engineering
8. Engineering Physics
9. Industrial Engineering

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

DIVISION OF BASIC STUDIES

ENGINEERING PROBLEMS AND METHODS

101. ***ENGINEERING PROBLEMS AND METHODS I.*** Credit 3 hrs. Fall. 1 Lect. 1 Rec. 1 Lab. Consideration of functions of engineering and major examples of modern engineering to emphasize the nature of engineering and the interrelationships of the several professional fields. Introduction to professional method in solution of engineering problems, graphical representation including sketching, descriptive geometry, and drafting.

102. ***ENGINEERING PROBLEMS AND METHODS II.*** Credit 3 hrs. Spring. 1 Lect. 1 Rec. 1 Lab. Solution of engineering problems; introduction to probability and statistics, introduction to engineering economy, continuation of graphical representation.

MATHEMATICS

191. ***CALCULUS FOR ENGINEERS.*** Either term. Credit 4 hrs. M T W Th 8, M W F S 8, M T W Th 9, M W F S 9, M T W Th 11, M W F S 11, M T W Th 12. Plane analytic geometry, differential and integral calculus applications.

192. ***CALCULUS FOR ENGINEERS.*** Spring term. Credit 4 hrs. Prereq., 191. Hours to be arranged. Analytic geometry in the plane and in space, partial differentiation, technique of integration and multiple integrals, applications.

293. ***ENGINEERING MATHEMATICS.*** Either term. Credit four hours. Prereq., 192. Hours to be arranged. Vectors and matrices, first-order differential equations, infinite series. Coding for electronic digital calculators will be taught and used for problems in the above topics.

294. ***ENGINEERING MATHEMATICS.*** Either term. Credit three hours. Prereq., 193. Hours to be arranged. Linear differential equations, quadratic forms and eigenvalues, differential vector calculus, applications.

PHYSICS

Physics 121–122 and 223–228 are designed primarily for students in the College of Engineering. The first year's work consists of 121 and 122; the second year's work consists of one of the two-term sequences 223–224, 225–226, or 227–228. The initial assignment to a given sequence in the second year will be made on the basis of the student's previous

performance in introductory physics and mathematics courses. Students should see their instructors for section assignments.

121–122. ***INTRODUCTORY ANALYTICAL PHYSICS.*** Throughout the year. Credit three hours a term. Prereq., calculus or coregistration 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 2½ hour laboratory period every other week, as assigned. Preliminary examinations will be held at 7:30 p.m. on Oct. 29, Dec. 3, Jan. 14, Mar. 17, Apr. 14, and May 19. Messrs. NEWHALL, MAHR, TALMAN, and Staff.

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,* Second Edition, Parts I and II, by Newhall.

223–224. ***INTRODUCTORY ANALYTICAL PHYSICS.*** Throughout the year. Credit 3 hrs. a term. Prereqs., Physics 122 and co-registration in Math. 293–294, or equivalent. Course 223 is prerequisite to 224. Lect., Th 9 or 11. Two discussion periods a week, and one 2½ hour laboratory period every other week, as assigned. Messrs. TOMBOULIAN, WEIDNER, SELLS.

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, and the electromagnetic field relations.

Wave motion with emphasis on the properties of electromagnetic waves; reflection, refraction and dispersion. Superposition of waves; interference, diffraction. Polarization.

Selected topics from contemporary physics such as special 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.

225–226. ***INTRODUCTORY ANALYTICAL PHYSICS.*** Throughout the year. Credit 3 hrs. a term. Prereqs., same as for Physics 223–224. Course 225 is prerequisite to 226. Lect., T 9 or 11. Two discussion periods a week, and one 2½ hour laboratory period every other week, as assigned. Messrs. TOMBOULIAN, DELVAILLE.

Includes the same topics (none omitted) as those listed under Physics 223–224, but their treatment is more analytical and somewhat more intensive. Same textbooks as in Physics 223–224.

227–228. ***INTRODUCTORY ANALYTICAL PHYSICS.*** Throughout the year. Credit 3 hours a term. Prereqs., same as for Physics 223–224. Course 227 is prerequisite to 228. Lect., S 11. Two discussion periods a week, and one 2½ hour laboratory period every other week, as assigned. Mr. FITCHEN and staff.

Includes the same topics (none omitted) as in Physics 223–224 and 225–226, but with a different amount of time devoted to each topic and generally each is treated at a sufficiently advanced level to stimulate high-ability students. At the level of *Introduction to Electricity and Optics* by Frank, of *Optics* by Rossi, and of some of *Principles of Modern Physics* by Leighton.

CHEMISTRY

103–104. ***INTRODUCTION TO CHEMISTRY.*** Throughout the year. Credit three hrs. 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 70, this course serves as prerequisite for Chemistry 205 or Chemistry 353. Lectures, M F 10 or 11. Combined discussion-laboratory period, T W or Th 8–11, M T W Th or F 1:40–4:30. Messrs. PORTER, GOLDSTEIN, and Assistants.

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 hrs. fall term and four hours spring term. Prerequisite, high school chemistry; 107 is prerequisite to 108. Recommended for those students who will

Note: Entering students exceptionally well prepared in chemistry may receive advanced credit for Chemistry 103–104 by demonstrating competence in the high school advanced standing 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.

take further courses in chemistry but do not intend to specialize in chemistry or closely related fields. Enrollment limited to 700. Lectures, T Th 9 or 10. 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. Messrs. PLANE, FAY, and Assistants.

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 simplified scheme of qualitative analysis.

115–116. ***GENERAL CHEMISTRY AND INORGANIC QUALITATIVE ANALYSIS.*** Throughout the year. Credit four hrs. a term. Prereq., high school chemistry at a grade of 85 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 350. Fall term: lectures, M W F 8; one three-hour combined discussion-laboratory period, T or Th 8–11, W or F 10–1, or W or F 1:40–4:30. Spring term: Lectures, M W 8; two three-hour combined discussion-laboratory periods, T Th 8–11, W F 10–1, or W F 1:40–4:30. Messrs. LAUBENGAYER, ZUCKERMAN, and Assistants.

A general study of the laws and concepts of chemistry based upon the more common elements, and application of the theory of chemical equilibrium to the properties and reactions of ions of the common elements and their separation and detection in solution.

276. ***INTRODUCTION TO PHYSICAL CHEMISTRY.*** Spring. Credit 3 hrs. Prereqs., Chemistry 106 or 108, Mathematics 193, and Physics 223, 225 or 227. For engineering students. A brief survey of physical chemistry. Mr. WIDOM.

285–286. ***INTRODUCTORY PHYSICAL CHEMISTRY.*** Replaces (405–406). Throughout the year. Credit 5 hrs. a term. Prereqs., Chemistry 108, Mathematics 192, Physics 122, or consent of instructor. For students in engineering. Lectures, M W F 9. Laboratories: fall, M 1:40–4:30 and T 10–12:50 or W Th 1:40–4:30 or S 8–1; spring, M T 1:40–4:30 or W Th 1:40–4:30 or F 1:40–4:30 and either S 8–10:50 or S 10–12:50. 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.

ENGLISH

111–112. ***INTRODUCTION TO ENGLISH.*** Throughout the year. Credit 3 hrs. a term. English 111 is prerequisite to English 112, M W F 8, 9, 10, 11, 12, 2, 3; T Th S 8, 9, 10, 11, 12. The aim is to increase the student's ability to communicate his own thought and to understand the thought of others. Messrs. SLATOFF, SMITH, and others.

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. ***ELECTRICAL SCIENCE I.*** Credit 3 hrs. Fall. 2 Lect. 1 (2½ hour) Rec.-Comp. The basic principles of electric and magnetic fields and circuits for steady fields, voltages, and currents. Emphasis is placed on understanding of the physical concepts.

242. ***ELECTRICAL SCIENCE II.*** Credit 3 hrs. Spring. 2 Lect. 1 (2½ hour) Rec.-Comp. Prereq., 241. Extends the treatment of 241 to time-varying fields, voltages, and currents. The relaxation and steady-state behavior of simple systems.

243. ***ELECTRICAL SCIENCE I.*** Credit 3 hrs. Fall. 2 Lect. 1 (2½ hour) Rec.-Comp. The main topics are the same as those in 241, but their treatment is more analytical and more intensive.

244. ***ELECTRICAL SCIENCE II.*** Credit 3 hrs. Spring. 2 Lect. 1 (2½ hour) Rec.-Comp. Prereq., 243. The main topics are the same as those of 242, but their treatment is more analytical and more intensive.

MECHANICS

211. ***MECHANICS OF RIGID AND DEFORMABLE BODIES I.*** Credit 4 hrs. Fall-spring. 1 Lec., 2 Rec., 1 Comp.-Lab. 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.

212. *MECHANICS OF RIGID AND DEFORMABLE BODIES II.* Credit 4 hrs. Spring. 1 Lect., 2 Rec., 1 Comp.-Lab. Prereq., 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.

CHEMICAL ENGINEERING

5101. *MASS AND ENERGY BALANCES.* Credit 3 hrs. 2 Lect., 1 Comp. period. Parallel, Physical Chemistry 405. Engineering problems involving material and heat balances. Flowsheet systems and balances. Total energy balances for flow systems. Messrs. WINDING, THORPE, SCHEELE.

5102. *EQUILIBRIA AND STAGED OPERATIONS.* Credit 3 hrs. Spring. 2 Lect. 1 Comp. period. Parallel, Physical Chemistry 406. Phase equilibria and phase diagrams. The equilibrium stage, mathematical description of single and multistage operations, analytical and graphical solutions. Messrs. WINDING, THORPE, SCHEELE.

ENGINEERING MECHANICS

211. *MECHANICS OF RIGID AND DEFORMABLE BODIES I.* Credit 4 hrs. Fall-spring. 1 Lect. 2 Rec. 1 Comp.-Lab. 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. Staff.

212. *MECHANICS OF RIGID AND DEFORMABLE BODIES II.* Credit 4 hrs. Spring. 1 Lect. 2 Rec. 1 Comp.-Lab. Prereq., 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. Staff.

1154 (1134). *ADVANCED MECHANICS OF MATERIALS.* Credit 3 hrs. Fall. 3 Lect. Beam theory including symmetric and unsymmetric bending, beam-columns, buckling, shear stresses, continuous beams, plastic bending, curved bars and beams on elastic foundations. Strength theories. Bending theory of circular and long rectangular plates, membrane and local bending theory for thin wall pressure vessels. Symmetrical deformation problems including the pressurized thick walled cylinder, shrink fit stresses, rotating discs and thermal stresses in long hollow cylinders. Mr. BIJLAARD.

1159. *EXPERIMENTAL MECHANICS.* Credit 3 hrs. Spring. 1 Rec. 2 Lab. Prereq., 1154 or equiv. 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. Mr. MOYNIHAN.

1162. *THEORY OF VIBRATION.* Credit 3 hrs. Fall. 3 Lect. Prereq., 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. Mr. PAO.

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. Mr. CONWAY.

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. Mr. CONWAY.

[**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 inte-

gral techniques in elasticity; torsion problems. Not offered in 1963–1964.]

1166. *STRESS WAVES IN SOLIDS.* Credit 3 hrs. Spring. 3 Lect. Prereqs., 1162, 1163 or equiv. 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 waveguides. Transient loads. Scattering of elastic waves and dynamical stress concentration. Waves in visco-elastic media. Mr. PAO.

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. Mr. BIJLAARD.

1168. *THEORY OF PLASTICITY.* Credit 3 hrs. Fall. 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. Mr. LANCE.

1169. *THEORY OF ELASTIC AND INELASTIC STABILITY.* Credit 3 hrs. Fall. 3 Lect. Graduate students and qualified undergraduates. Various cases of instability. Derivation of elastic and inelastic buckling loads of columns with various boundary and continuity conditions, truss members, frames, etc., by various methods, such as direct solution from differential equations as eigenvalue problems, by Haarman method, energy methods, matrix method using digital computer. Buckling of composite structures such as columns with batten plates, latticed columns by Haarman method and method of split rigidities. Buckling of plates with various boundary conditions. Solutions for buckling of plate assemblies by solving of differential equations and by method of split rigidities. Theory of inelastic buckling of plates and shells. Buckling and forced crippling of stringerpanels in airplane wings. Interaction of column and plate buckling. Buckling of sandwich plates with various boundary conditions. Derivation of post-buckling load of plates. Buckling load of columns in the post-buckling range of the composite plates. Buckling of cylindrical, spherical and conical shells under external pressure. Cylindrical shells evenly stiffened by rings. Cylindrical shells under axial compression and bending. Buckling of sandwich shells. Mr. BIJLAARD.

1170. *ADVANCED DYNAMICS.* Credit 3 hrs. Fall. 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, Legrange's equations, Hamilton's equations. Stability of motion, Liapunov's method. Rigid body motion, Euler's equations, tops, gyroscopes. Theory of small oscillations. Mr. CRANCH.

[**1171. *SPACE MECHANICS.*** Credit 3 hrs. Spring. 3 Lect. Prereq., 1170 or equivalent. Potential of earth; two-body problem; Hamilton Jacobi theory; orbit about spherical and nonspherical earth; vector theory of perturbations; drag and solar radiation effect on orbit; charged satellite in earth's magnetic field; restricted three-body problem; libration points; reflectibility and reversibility of trajectories; attitude control of satellites; satellite libration. Not offered in 1963–1964.]

1172. *SELECTED TOPICS IN ENGINEERING MECHANICS.* Credit as arranged, any term. Qualified students wishing to do work in any field of engineering 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. Staff.

1173. *RESEARCH IN APPLIED MECHANICS.* Credit as arranged. Thesis or independent research in a field of applied mechanics. Such research must be under the guidance of a staff member. Staff.

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 Bogolioboff, Galerkin, Ritz, harmonic balance, equivalent linearization, graphics, perturbations. Hysteresis. Application of Banach space techniques. Mr. BLOCK.

1180. *MATHEMATICAL METHODS IN ENGINEERING I.* Credit 3 hrs. Fall. 3 Lect. Prereq., 1155 or equivalent. Application to engineering problems of elementary differential equations, Laplace and Fourier transforms, series, orthogonal functions, functions of several real variables, vector analysis, partial differential equations. Mr. BLOCK.

1181. *MATHEMATICAL METHODS IN ENGINEERING II.* Credit 3 hrs. 3 Lect. Spring. Prereq., 1180. Applications to engineering problems of calculus of variations, tensor analysis, complex variable, matrices, difference equations, and integral equations. Mr. LUDFORD.

1182. *MATHEMATICAL METHODS IN ENGINEERING III.* Credit 3 hrs. Fall. 3 Lect. Prereq., 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; boundary-layer analysis. Development will be in terms of problems drawn from vibrations and acoustics, fluid mechanics and elasticity, heat transfer, electromagnetics. Mr. LUDFORD.

1183. *MATHEMATICAL METHODS IN ENGINEERING IV.* Credit 3 hrs. Spring. 3 Lect. Prereq., 1182 or equivalent. More extensive treatment of 1182 in same spirit. Topics include: advanced methods in partial differential equations, WKB and PLK approximations, Hilbert-Schmidt and Fredholm theories of integral equations, singular integral equations, Hilbert problem, dual integral equations. Mr. LUDFORD.

1184. *NUMERICAL METHODS IN ENGINEERING.* Credit 3 hrs. Spring. Prereq., 1181 or equivalent. Methods for obtaining numerical solutions to problems arising in science and engineering, such as boundary value problems, eigenvalue problems, diffusion, conduction, wave propagation, vibrations. Variational and integral equation techniques are developed. Mr. LANCE.

1198, 1199. *PROJECT.* Total credit 6 hrs. Work of the ninth and/or tenth terms in the form of projects designed to integrate the student's training in several engineering areas when such work is done principally in the field of engineering mechanics. Staff.

CIVIL ENGINEERING

CIVIL ENGINEERING MATERIALS

Mr. SLATE

2002. *ENGINEERING MATERIALS.* (Old 1212) Credit 3 hrs. Spring. 2 Lect. 1 Lab. Prereq., 6311. Design and engineering properties of concrete; engineering properties of steel and other selected structural metals, wood; physico-chemical properties of soils, and bituminous materials. Design characteristics and significance of test results of materials used in engineering works. Extensive laboratory testing and report writing. First taught spring 1964.

2010. *ADVANCED PLAIN CONCRETE.* (Old 1217) Credit 2 hrs. Spring. 2 Lect. Prereq., 2002 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.* (Old 1216) Credit 2 hrs. Fall. 2 Lect. Open to graduate students in engineering or the physical sciences or by consent of instructor. Internal structure of materials ranging from the amphorous to the crystalline state. Correlation of the internal structures of materials with their physical and mechanical properties, primarily on a qualitative basis. Applications to metals and other engineering materials.

2044. *SPECIAL TOPICS IN MATERIALS.* On demand. Fall-spring. Hours and credit variable.

SURVEYING

Messrs. ANDERSON, BROCK, LYON, MCNAIR, and others.

2101. *ENGINEERING MEASUREMENTS.* Credit 3 hrs. Spring. 2 Rec. 1 Lab. Study of basic surveying instruments and of linear, angular, and area measuring procedures; data processing and presentation of results of measurement operations; topographic surveys by terrestrial methods; and geometry of circular, transition, and parabolic curves.

[**2102. *ADVANCED SURVEYING.*** Credit 2 hrs. Fall. 1 Rec. 2 Labs. Prereq., 2101. Project planning from topographic maps; photogram-

metry; measurement errors and statistics; conditioned measurements; formulation of survey specifications; subsurface surveys; hydrographic surveys; geodesy; field astronomy; and boundary surveys. First offered in fall 1964–1965.]

2107. *ELEMENTS OF SURVEYING.* Credit 2 hrs. Fall-spring. 1 Rec. 1 Lab. Fundamentals of engineering measurements. Appreciation of observations and errors. Principles of recording data. Use of steel tape, level, and transit. Optical tooling. Problems of particular interest to students in fields other than civil engineering.

2108. *SURVEYING.* Credit 3 hrs. Spring. 2 Rec. 1 Lab. Fundamentals of engineering measurements. Appreciation of methods of observations and errors. Principles of recording data. Use of steel tape, level, transit, and plane table. Aerial mapping. Emphasis on problems common in agricultural engineering.

2111. *GEODETIC SURVEYING.* Credit 3 hrs. On demand. 3 Rec. Prereq., permission of the instructor. Consideration of special problems in geodetic surveying; base line; triangulation; traverse; precise leveling; deflection of the plumb line; figure of the earth; determination of gravity; isostasy; magnetic properties of the earth. Subject to arrangement to meet the special needs of students.

2112. *ADVANCED ENGINEERING MEASUREMENTS.* Credit 3 hrs. Fall. Prereqs., 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 data processing methods.

2113. *MAP PROJECTION.* Credit 3 hrs. On demand. The theory of map projections. Construction of projections. Plane coordinate systems.

2117. *VERTICAL CONTROL.* Credit 3 hrs. On demand. Lectures, reading, and field work. Principles of establishing a geodetic sea-level datum; isostasy, the geoid, and reference ellipsoid; barometric, trigonometric, spirit, and electronic leveling; study of precision altimetry; determination of economic relationships of vertical control methods to mapping scale, especially for photogrammetric mapping.

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, radial-line control, simple stereoplotting instruments, parallel distortions, graphical tilt determination, trimetrogen charting, and economics. A Balplex projection stereoplotter with three projectors and a Wild A-7 plotter are available for use.

2122. *ADVANCED PHOTOGRAMMETRY.* Credit 3 hrs. Spring. Prereq., 2121. Lectures, reading, and laboratory work. An advanced study of photogrammetric principles including controlled mosaics, rectification, graphical, mechanical, and analytical, space orientation. Readings and reports from current technical literature. The principles of many photogrammetric plotters are studied together with the economic relation of these instruments to density of field control, office methods, and personnel. The Balplex plotter and the Wild A-7 Autograph plotter with the attached EK-3 Electric Coordinate Printer are available for study and use.

2128. *SURVEYING AND MAPPING INSTRUMENTATION.* Credit 3 hrs. On demand. Prereq., 2121. Lectures and assigned reading. Independent study of developments in surveying, mapping, and photogrammetric instruments including a brief historical sketch of instrumentation; optical-reading levels and transits; electronic base line measurement; precision altimeters; sonar equipment; equiangulator, odograph, and stereoscopic plotters. Correlation of the principles of physics and mathematics in new measuring instruments and methods.

2131. *LAND SURVEYING.* Credit 3 hrs. On demand. 3 Rec. Prereq., permission of the instructor. 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.* Credit 2 hrs. On demand. A study of the needs of map users; and of the production of maps to meet these needs.

2133. *ROUTE AND CONSTRUCTION SURVEYS.* Credit 3 hrs. On demand. Prereq., 2102. Circular curves, transition curves, earthwork measurement and calculation, construction surveys and project planning from maps.

2134. *SUMMER SURVEY.* (Topographic, Hydrographic, Route, and Geodetic Survey Camp.) Credit 5 hrs. Field and office work six days a week for five weeks. Date to be an-

nounced in spring term. Prereqs., 2101 and 2102. Design and execution of topographic survey and corresponding map with emphasis on transit-stadia methods; hydrographic survey and map of Cayuta Lake; and complete route survey including reconnaissance from aerial photographs, preliminary survey, paper location, and staking of the final line. All horizontal and vertical control surveys are executed according to present standards for base-line taping, triangulation with repeating and direction type optical-reading thedolites, subtense and trig traverse, precise leveling, and altimetry. Astronomic observation for azimuth and position are made and results computed.

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. Prerequisities 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.*** Credit 1–6 hrs. On demand. 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

Messrs. Brutsaert, Graf, Liggett, and staff.

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. Staff.

2302. ***HYDRAULIC ENGINEERING.*** Credit 3 hrs. Spring. 2 Rec. 1 Lab. Prereq., 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. Mr. Graf.

2303. ***HYDROLOGY.*** (Old 2302) Credit 2 hrs. Fall. 2 Lect.-Rec. Prereq., 2301. Introduction to hydrology including topics on precipitation, evapotranspiration, ground water, surface water, and sedimentation. Mr. Brutsaert.

2309. ***HYDRAULIC ENGINEERING.*** (Old 2312) To be taken by those students who have had 2301 prior to fall 1963. Offered for the last time spring 1964. Credit 3 hrs. Fall-spring. 3 Lect.-Rec. Prereq., 2301. Introduction to hydraulic engineering problems. Purpose, planning, and component parts of hydraulic projects. Flow measurement, unsteady flow. Reservoirs, dams, spillways, and river protection works. Flumes and channels. Conduits, tunnels, penstocks. Locks. Hydraulic model studies. Staff.

2311. ***ADVANCED HYDRAULICS.*** Credit 3 hrs. Fall. 3 Rec. Prereq., 2301. Intended as an extension of the elementary fluid mechanics. Primarily for students not majoring in civil engineering or those who have not received their undergraduate training at Cornell. Basic equations, potential flow, flow in conduits, boundary layer theory, open channel flow, water hammer and surges, hydraulic models, and compressible flow. Special problems. Staff.

2312. ***EXPERIMENTAL METHODS IN FLUID MECHANICS.*** Credit 2 hrs. Fall-spring. Prereq., 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. Each section is limited to 4 students. Staff.

2313. ***HYDRAULIC MACHINERY.*** Credit 3 hrs. Fall. 2 Rec. 1 Lab. Prereq., 2302. Theory and characteristics of the hydraulic ram; reciprocating and centrifugal pumps; impulse, reaction and propeller type turbines. Selection and testing of hydraulic machinery. Staff.

2314. ***RIVER AND HARBOR HYDRAULICS.*** Credit 3 hrs. Fall. Prereq., 2302 and 2303 or permission of instructor. River hydraulics, fluvial hydraulics and problems in sedimentation coastal engineering and harbor hydraulics. Mr. Graf.

2315. ***ADVANCED FLUID MECHANICS I.*** Credit 3 hrs. Fall. 3 Rec. Prereq., 2301. Introduction to vector and tensor notation. The equations of conservation of mass, momentum, and energy from a rigorous point of view. Potential flow including circulation, vorticity, conformal mapping, and hodograph methods. Mr. Liggett.

2316. ***ADVANCED FLUID MECHANICS II.*** Credit 3 hrs. Spring. 3 Rec. Prereq., 2315. Exact solutions to the Navier-Stokes equations, the laminar and turbulent boundary layers, turbulence, introduction to non-Newtonian flow, and other topics. Mr. Liggett.

2317. ***FREE SURFACE FLOW.*** Credit 3 hrs. Spring. 3 Rec. Prereq., 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. Mr. LIGGETT.

2320. ***SURFACE-WATER HYDROLOGY.*** Credit 2 hrs. Fall. 2 Rec. Prereq., 2301. Physical analysis and design relative to hydrologic processes. Hydrometeorology, runoff, forecasting and control of floods, unit-hydrography procedures, channel and reservoir routing. Mr. BRUTSAERT.

2321. ***FLOW IN POROUS MEDIA.*** Credit 3 hrs. Spring. Prereq., 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. Mr. BRUTSAERT.

2341. ***PROJECT.*** Hours and credit variable. Offered on demand. The student may elect a design problem or undertake the design and construction of a special piece of equipment in the fields of fluid mechanics, hydraulic engineering or hydrology.

2342. ***RESEARCH IN HYDRAULICS.*** Hours and credit variable. Offered on demand. 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 are presented and discussed.

2344. ***SPECIAL TOPICS IN HYDRAULICS.*** Hours and credit variable. Offered on demand. Special topics in fluid mechanics, hydraulic engineering, or hydrology are presented when a group of students expresses an interest or when an especially qualified person appears on campus.

SOILS ENGINEERING

Messrs. BROMS, ESRIG.

[2401. ***ELEMENTS OF SOILS ENGINEERING.*** Credit 4 hrs. Fall. 3 Lect. 1 Lab. Properties of soil and its behavior as an engineering material. Principles of soil identification and classification, terminology and soil characteristics such as gradation, permeability, compressibility, consolidation, and shearing strength with application to simple problems of seepage, settlement, bearing capacity, stability of earth slopes. Lateral earth pressure. Soil exploration. Laboratory tests for experimental determination of above-mentioned soil characteristics, and evaluation and use of data. Offered for the first time in fall 1964.]

2402. ***ELEMENTS OF SOILS ENGINEERING.*** **(Old 2725)** Credit 3 hrs. Fall-spring. 2 Lect. 1 Lab. This course will be superseded by 2401. It will be offered for the last time in fall 1963. Properties of soil and its behavior as an engineering material. Principles of soil identification and classification, terminology and soil characteristics such as gradation, permeability, compressibility, consolidation, and shearing strength. Laboratory tests for experimental determination of above mentioned soil characteristics.

2406. ***FOUNDATIONS.*** **(Old 2720)** Credit 3 hrs. Fall-spring. 2 Lect. 1 Lab. Prereqs., 2715, 2401 or 2402. Study of the structural problems encountered in foundation work. Retaining walls, sheet piling, spread footings, piles, piers, abutments, cofferdams, caissons, underpinnings. Design problems. Mr. ESRIG.

2410. ***ENGINEERING PROPERTIES OF SOILS.*** **(Old 2726)** Credit 3 hrs. Fall. 3 Lect. Prereq., 2401 or 2402. Soil structure, adsorbed and free water. Flow of water through soil, flow nets, piezometers, filters, piping, capillary flow, soil suction, and frost action. Uniaxial and triaxial consolidation, volume compressibility and pore pressure coefficients, shrinkage and swelling. Shear strength of saturated and partly saturated, isotropically and anisotropically consolidated soils, true and apparent cohesion and friction resistance, sensitivity and trixotrophy, triaxial, direct shear, penetration and vane tests. Mr. ESRIG.

2412. ***PRINCIPLES OF SOILS ENGINEERING.*** **(Old 2727)** Credit 3 hrs. Fall. 3 Lect. Prereq., 2401 or 2402. Failure theories for soils, general and local shear failures, Kotter's equation and boundary conditions. Lateral earth pressures, Rankine, Coulomb, logarithmic spiral and friction circle methods. Bearing capacity of deep and shallow foundations, eccentric and inclined loading, size and shape effects. Stability of slopes, methods of slices, seepage pressures. Soil pressures, concentrated and distributed loads, influence charts, soil modulus, contact pressures, and pressure cells. Mr. BROMS.

2414. *APPLIED SOILS ENGINEERING.* (Old 2728) Credit 3 hrs. Spring. 3 Lect. Prereqs., 2401 or 2402 and 2412. Long and short-time strength of soils, numerical methods. Footings and rafts, design criteria, elastic foundations, construction problems, plate load tests. Piles and caissons, pile tests, pile driving formulas, dynamic and static penetration tests, ultimate strength and settlements of pile groups, stress wave equation, buckling and lateral resistance. Retaining walls, shallow and deep-seated failures, seepage pressures. Mr. BROMS.

2416. *APPLIED SOILS ENGINEERING.* (Old 2729) Credit 2 hrs. Spring. 2 Lect. Prereq., 2412 or consent of instructor. Soil exploration and sampling including geophysical methods as applied to foundation, construction and ground water problems. Design of boring programs and interpretation of field data. Bulkheads and bracing, design criteria, behavior at ultimate and working loads, design of earth and rock fill dams, upstream and downstream slopes, flow nets, concept of safety and load factors. Design and stability evaluation of cofferdams, effects of construction procedures on lateral earth pressures. Tunnels, geological considerations, factors affecting tunnel lining design, special problems. Mr. BROMS.

2418. *EVALUATION OF SOIL PROPERTIES.* (Old 2730) Credit 3 hrs. Spring. 1 Lect. 2 Labs. Prereq., 2410 or consent of instructor. Laboratory evaluation of the parameters used in modern soil mechanics and soil engineering. Emphasis is placed on the relationship of these measured parameters to those needed in design. Consideration is given to the effects of sampling methods on the soil parameters. Experiments include permeability, direct shear, triaxial and consolidation testing. Mr. ESRIG.

2441. *PROJECT.* On demand. Projects may be selected from the various fields of soils engineering such as shear strength and consolidation characteristics of soils, stabilization, soil-structure interaction, behavior of soils under dynamic loads, etc. Also, design problems such as pile foundations, sheet pile walls, earth or rock fill dam tunnels, cofferdams may be chosen which are of particular interest to the student. Hours and credit variable.

2442. *SOILS ENGINEERING RESEARCH.* On demand. Credit 1–6 hrs. Students who wish to study one particular area in soils engineering to some depth. The work could be in the form of a laboratory investigation, theoretical analysis of the behavior and failure modes of earth structures or the development of design methods.

2443. *SOILS ENGINEERING SEMINAR.* On demand. Credit 1–2 hrs. Presentation and discussion of technical papers and current research in the field of soils engineering. Open to seniors and graduate students.

2444. *SPECIAL TOPICS IN SOILS ENGINEERING.* On demand. Credit 1–6 hrs. Supervised studies in small groups (2–3 students) in one or more of the special topics in the field of soils engineering which are not covered in the regular courses. Hours and credit variable.

SANITARY ENGINEERING

Messrs. BEHN, GATES, LYNN, WOOLHISER, and staff.

[**2501. *WATER AND WASTE-WATER TREATMENT.*** Credit 4 hrs. 3 Lect.-Rec. 1 Lab. Fall-spring. Prereq., 2301. Study of the microbiological, chemical and physical phenomena underlying the treatment of water supplies and of municipal and industrial wastewater. Application of these principles to the analysis and design of unit treatment processes and to the synthesis of treatment plants. Laboratory measurement of water and of wastewater quality. Offered for the first time in fall 1964.]

2502. *SANITARY ENGINEERING SYSTEMS.* Credit 3 hrs. 2 Lect.-Rec. 1 Comp. Fall-spring. Prereqs., 2302, 2303, 2501. Introduction to water resource systems. Analysis and design of (1) municipal water distribution systems (2) waste-water and storm-water collection, transportation and disposal systems. Concepts and principles applicable to the dispersion and stabilization of municipal, industrial and radioactive wastes in water and in air. Concepts of comprehensive water quality control. Offered for the first time in spring 1965.

2503. *WATER AND WASTE-WATER TREATMENT.* To be taken only by students who entered Civil Engineering before Sept. 1963. Offered for the last time in spring 1964. Credit 3 hrs. 2 Lect.-Rec. 1 Lab. or Comp. Study of processes for the treatment of water supplies and of municipal and industrial wastewater, in terms of the underlying biological, chemical, and physical principles; the application of these principles to the analysis and design of unit treatment processes and to the synthesis of treatment plants.

2504. *WATER SUPPLY AND WASTE-WATER SYSTEMS.* (Replaces 2502). To be taken only by those students who entered Civil Engineering before September 1963. Offered for the last time in fall 1963. Credit 3 hrs. Fall-spring. 2 Lect.-Rec. 1 Comp. Prereq., 2302. Concepts of water resource development and utilization; water quality control; analysis and design of structures and systems for (1) the collection, transportation, and distribution of

water supplies (2) the collection, transportation and disposal of municipal and industrial waste-water and of storm water.

2509. ***ENVIRONMENTAL SANITATION.*** Open to non-civil engineering students. Credit 3 hrs. Fall. Lect.-Discuss., reports and field trips. Concepts of environmental health and their application to municipal and metropolitan sanitation. Introduction to water resource systems; water supply systems; municipal, industrial and private waste-water disposal systems; disposal of solid wastes; radiological health; air and water quality control; particularly as these principles and methods apply to environmental health planning and control.

2510. ***CHEMISTRY OF WATER AND WASTE WATER.*** Credit 3 hrs. 2 Lect.-Rec. 1 Lab. Fall. Prereq., 1 year of college chemistry. Principles of chemistry applicable to the understanding, design, and control of water and waste-water treatment processes. Analytical methods applicable to the measurement and control of air and water quality.

2511. ***SANITARY ENGINEERING LABORATORY.*** Credit 3 hrs. On demand. 1 Lect. 2 Labs. Prereq., 2510 or parallel registration, 2501. Laboratory studies of microbiological, chemical and physical phenomena, processes and methods applicable to the treatment of water and waste-water.

2512. ***MICROBIOLOGY OF WATER AND WASTE-WATER.*** Credit 3 hrs. 2 Lect.-Rec. 1 Lab. Fall. Introduction to the characteristics, activities, and control of microorganisms. Their effect on the environment and their role in the biological oxidation of organic substances in waste-water treatment plants and in receiving waters. Biological and bacteriological parameters of water quality and their measurement.

2513. ***TREATMENT PROCESSES.*** Credit 3 hrs. 3 Lect.-Rec. Fall. Prereq., 2501 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 AND IN AIR.*** Credit 3 hrs. 3 Lect.-Rec. Spring. Prereq., appropriate undergraduate course. Capacity of air and of water resources to assimilate gaseous, liquid and particulate wastes. Phenomena pertinent to the dispersion and stabilization of wastes in air and in water. Analog computer methods. Emphasis on the advanced literature.

2515. ***WATER RESOURCE PLANNING AND DEVELOPMENT.*** Credit 3 hrs. 3 Lect.-Discuss. Open to engineers and non-engineers interested in a comprehensive approach to water resources. An introduction to the economic, administrative and legal aspects of water resource planning, development and management and to the problems associated with each.

2517. ***ENVIRONMENTAL SYSTEMS ENGINEERING I.*** Credit 3 hrs. 3 Lect.-Rec. Fall. Prereq., permission of the instructor. Intended for graduate students but open to qualified undergraduates. Development of general linear programming problem and special cases such as networks, dyadics, transportation problem. Emphasis placed on application of techniques of operations research, queuing theory, dynamic programming, simulation, game theory, and linear programing to civil and sanitary engineering problems.

2518. ***ENVIRONMENTAL SYSTEMS ENGINEERING II.*** Credit 3 hrs. 3 Lect.-Rec. Spring. Prereq., permission of the instructor. Advanced topics in the analysis of water resource, sanitary engineering, and environmental engineering systems.

2520. ***ENVIRONMENTAL HEALTH ENGINEERING.*** Credit 3 hrs. 3 Lect.-Rec., reports. Spring. Prereq., 2501 or equivalent or permission of the instructor. Concepts and methods of environmental health planning and control; their application to metropolitan sanitation, air and water quality control, the disposal of solid wastes. Principles of epidemiology and toxicology. Introduction to radiological health.

2541. ***PROJECT, SANITARY ENGINEERING.*** On demand. Credit variable. Prereqs., 2501 and 2502 or equivalent. The student will elect or be assigned specific problems in the design of water and waste-water treatment processes and plants; water distribution systems; waste-water disposal systems; water quality control systems; or of other sanitary engineering processes or laboratory apparatus of special interest.

2542. ***SANITARY ENGINEERING RESEARCH.*** On demand. Credit variable. Prereqs. 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. These studies are not limited to the laboratory.

2543. ***SANITARY ENGINEERING SEMINAR.*** Credit 1–2 hrs. Fall-spring. Required of all graduate students taking a major or minor in sanitary engineering; open to undergrad-

uates by permission of instructor. Preparation, presentation, and discussion of topics and problems of current interest in sanitary engineering and water resources.

TRANSPORTATION ENGINEERING

Messrs. Belcher, Hewitt, Lewis, Liang, Slate.

[2601. ***TRANSPORTATION ENGINEERING.*** Credit 4 hrs. Fall-spring. 3 Rec. 1 Lab. Prereq., preceded by or taken concurrently with 2101 and 2401. Transportation systems, traffic and operation, environmental investigations, transportation planning, highway engineering, other transportation modes, discussions of current issues. Staff. Offered for the first time in fall 1964.]

2602. ***TRANSPORTATION.*** Credit 3 hrs. Fall-spring. 3 Rec. Prereq., Economics 103 or permission of the instructor. The historical, economic, regulatory, construction, and operational aspects of transportation. Designed particularly for engineering students. Mr. Lewis. Will not be taught after fall 1963.

2610. ***HIGHWAY ENGINEERING.*** Credit 3 hrs. Fall-spring. 2 Lect. 1 Lab. Prereqs., 2113, and preceded by or taken concurrently with 2425. Highway administration, planning, economics, and finance; reconnaissance and location; geometric design, traffic engineering; drainage; subgrade; base courses, design and construction of flexible and rigid pavements. Mr. Liang. Will not be taught after spring 1964.

2612. ***HIGHWAY LABORATORY — BITUMINOUS.*** Credit 3 hrs. Fall. 2 Lab. 1 Seminar. Prereq., 2601, or may be taken concurrently with 2601. Bituminous materials are tested and aggregates studied for their compatibility with bitumens. Mixes are designed and tested. Condition surveys are made on various classes of bituminous pavements. Laboratory fully equipped for all phases of applied and research studies. Mr. Hewitt.

2613. ***HIGHWAY LABORATORY — SUBGRADE SOILS.*** Credit 3 hrs. Spring. 2 Lab. 1 Seminar. Prereqs., 2425 and 2601, or may be taken concurrently with 2601. 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. Mr. Liang.

2616. ***HIGHWAYS AND AIRPORTS.*** **(Old 2614–17)** Credit 3 hrs. Spring. 3 Rec. Prereq., 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. Mr. Liang. Will not be taught until spring term 1964.

2618. ***LOW-COST ROADS.*** Primarily for foreign students. Credit 3 hrs. On demand. (See Agricultural Engineering 241.)

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. On demand. Organization of course depends upon fields of interest. Special problems: four each on ground water, engineering projects, agricultural soils mapping, irrigation, and geology. Mr. Belcher.

2626. ***TRAFFIC ENGINEERING.*** **(Old 2620)** Credit 3 hrs. Fall-spring. 2 Rec. 1 Lab. Prereq., 2601 or 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. Mr. Lewis.

2627. ***TRAFFIC ENGINEERING — OPERATIONS.*** **(Old 2619)** Credit 3 hrs. On demand. 2 Lab. 1 Seminar. Prereq., 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. Mr. Lewis.

2628. ***HIGHWAY GEOMETRIC DESIGN.*** **(Old 2615)** Credit 3 hrs. Spring. 1 Lect. 2 Lab. Prereq., 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, freeways, and parkways. Mr. LEWIS.

2631. ***PHYSICAL ENVIRONMENT EVALUATION.*** **(Old 2623)** 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. Mr. LIANG.

[2632. ***ADVANCED PHYSICAL ENVIRONMENT.*** **(Old 2624)** Credit 3 hrs. On demand. Mr. LIANG. Will not be taught until spring 1965.]

2641. ***TRANSPORTATION ENGINEERING PROJECT.*** Credit 3 hrs. On demand. 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. 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. Hours and credit variable.

2643. ***TRANSPORTATION ENGINEERING SEMINAR.*** Credit 1–2 hrs. On demand. 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.*** Credit varies. On demand.

STRUCTURAL ENGINEERING

Messrs. BRITVEC, ERRERA, FISHER, MCGUIRE, NILSON, STEARNS, WHITE, WINTER.

2701. ***STRUCTURAL ENGINEERING I.*** Credit 3 hrs. Fall. 2 Lect. 1 2-hour period. Prereqs., 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. Applications of digital computers to analysis and design. First taught in fall 1963. Staff.

2702. ***STRUCTURAL ENGINEERING II.*** Credit 3 hrs. Spring. 2 Lect. 1 2-hour period. Prereq., 2701, Mat. Sci. I, and conc. reg. in Engineering Materials. Analysis of simple trusses under fixed and moving loads. Approximate analysis of building frames. Materials strength theories. Properties and behavior of reinforced concrete. Behavior under load of reinforced concrete beams, columns, and beam columns, including effects of prestressing. Computer applications. First taught in spring 1964. Staff.

[2703. ***STRUCTURAL ENGINEERING III.*** Credit 3 hrs. Fall. 2 Lect. 1 2-hour period. Prereq., 2702, Eng. 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. Staff. Offered for first time in fall 1964.]

[2704. ***STRUCTURAL ENGINEERING IV.*** Credit 3 hrs. Spring. 2 Lect. 1 2-hour period. Prereq., 2703. Extension of previous material on steel and concrete, including various design considerations and critical code discussions. Behavior and design of connections. Membrane theory of shell structures. Structural model analysis. Synthesizing problems drawing on material from all four courses. Staff. Offered for first time in spring 1965.]

2705. ***STATICALLY INDETERMINATE STRUCTURES.*** **(Old 2704)** Credit 4 hrs. Fall. 3 Lect. 1 Lab. Deflections. Classical and modern methods of analysis of statically indeterminate beams, frames, trusses. Influence lines, plastic design and analysis of steel structures. Offered for last time in 1963–1964.

2707. ***ELEMENTS OF STRUCTURAL ENGINEERING I.*** **(Old 2731)** For students not in Civil Engineering. Credit 3 hrs. Fall. 2 Lect. 1

Lab. Analysis of statically determinate and simple statically indeterminate structures. Determination, by means of analytical and graphical methods, of reactions and internal forces and moments caused by stationary loads. Influence lines for beams. Staff.

2708. ***ELEMENTS OF STRUCTURAL ENGINEERING II.*** **(Old 2732)** For students not in Civil Engineering. Credit 3 hrs. Spring. 2 Lect. 1 Lab. Prereq., 2707. Design of simple steel and timber structures. Discussion of design in light gage steel and aluminum. Analysis and design of members and connections, roof trusses, floor systems, and other structures. Staff.

2710. ***STRENGTH OF STRUCTURES.*** Credit 3 hrs. Fall. 3 Rec. Prereq., 2705; can be taken concurrently. Analysis of two- and three-dimensional stress and strain. Theories of failure of ductile and brittle materials. Strain energy methods applied to bending, shear, and impact. Structural materials under load, strain hardening, residual stresses, hysteresis, stress concentration, brittle fracture, 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. Mr. WINTER.

2711. ***BUCKLING: ELASTIC AND INELASTIC.*** Credit 3 hrs. Spring. Prereq., 2710. Analysis of elastic and plastic stability. Determination of buckling loads and maximum stresses of columns with and without eccentricity. Solid and open web columns with variable cross-section. Beam columns. Frame 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. Mr. WINTER.

2712, 2713. ***ADVANCED STRUCTURAL ANALYSIS.*** **(Old 2708, 2709)** Credit 3 hrs. a term. Fall-spring. 3 Lect. a week throughout the year. Prereq., 2705 or equivalent. Review of fundamental methods of analyzing indeterminate structures and extension to complex structural systems. Arches, curved beams, out-of-plane loading, suspension structures, trussed and rigid space frames, etc. Elastic model analysis, numerical methods, matrix solution of structures, use of digital computers in analysis and design. Mr. FISHER.

2714. ***EXPERIMENTAL AND NUMERICAL METHODS IN STRUCTURAL ENGINEERING.*** Credit 3 hrs. Fall. 3 Lect. Prereq., differential equations, indeterminate analysis, and consent of instructor. Dimensional analysis and interpretation of experimental data. Indirect model analysis of beams and frames using deformeters. Direct model analysis of structural forms, including principles of strain measurement and interpretation. Laboratory projects in elastic behavior and ultimate strength of model structures. Applications of numerical methods (roots of equations, matrix algebra, eigenvalue determination, finite differences and linear equations, and other topics) to structural problems, stressing solution by digital computer techniques. Mr. WHITE.

2715. ***REINFORCED CONCRETE DESIGN.*** Credit 4 hrs. Fall-spring. 2 Lect. 2 Lab. Prereq., 2705. A first course in reinforced concrete. Linear and ultimate strength theory of reinforced concrete applied to rectangular beams, one- and two-way slabs, T-beams, beams reinforced for compression, concentric and eccentric columns. Shear and bond. Design project comprising partial design of concrete building frame. Introduction to prestressed concrete. Offered for last time in 1963–1964.

2716. ***BEHAVIOR AND DESIGN OF CONCRETE STRUCTURES.*** Credit 3 hrs. Prereq., 2705 or equivalent. Theory, behavior, and design of prestressed concrete and continuous reinforced concrete frameworks. Limit design. Staff.

2717. ***ADVANCED CONCRETE DESIGN.*** Credit 3 hrs. Prereq., 2716. Reinforced and prestressed slab, plate and shell structures. Theory, behavior, design. Critical analysis of design codes. Staff.

2718. ***BEHAVIOR AND DESIGN OF METALS STRUCTURES.*** Credit 3 hrs. Prereq., 2704 or equivalent. Elastic and plastic design of framed structures, including wind and earthquake effects. Bridge types and economy. Mr. MCGUIRE.

2719. ***ADVANCED METALS STRUCTURES DESIGN.*** Credit 3 hrs. Prereq., 2718. Steel plate structures, suspension roof systems, composite bridges, lightweight alloy structures. Critical review of recent research and specifications. Mr. MCGUIRE.

[2720. ***SHELL THEORY AND DESIGN.*** Not given in 1963–1964.]

2721. ***STRUCTURES IN NUCLEAR ENGINEERING.*** **(Old 2736)** Credit 3 hrs. Pressure vessel analysis and associated design codes. Thermal stresses including internal heat generation effects. Material properties which influence structural design. Analysis and design of nuclear reactor components; core, fuel elements, primary containment, shielding, second-

ary containment. Structures to resist nuclear weapons effects.

2722. ***DYNAMICS OF STRUCTURES.*** **(Old 2735)** Credit 3 hrs. Fall-spring. For graduate students or qualified undergraduates. Dynamic behavior of structures as caused by blasts, earthquakes, and similar actions. Lumping of masses. Motion of elastic framed structures in the neighborhood of equilibrium positions, caused by arbitrary disturbances. Systems with one degree of freedom. Resonance and stability. Analytical and numerical methods of solution. Energy methods, Hamilton's principle. Lagrange's equations of motion. Natural frequencies and normal modes of vibration of multidegrees of freedom-systems. Matrix iteration method. The Rayleigh-Ritz method for the approximate determination of natural frequencies of elastic systems. Dynamic response of framed structures in the inelastic range. Free and forced, longitudinal and transverse vibrations of simple and continuous elastic beams. Effect of axial forces on lateral vibrations of beams. Torsional-flexural vibrations of simple beams of open thin-walled sections.

[**2733.** ***STRUCTURAL SYNTHESIS AND PLANNING.*** Not given in 1963–1964.]

2741. ***PROJECT IN STRUCTURAL ENGINEERING.*** On demand. The student may select a design problem such as an arch bridge, cantilever or rigid frame bridge, a special problem in steel or concrete building design, or the design of any other structure of particular interest to the student provided he has the proper preparation for such design. The work is submitted in the form of reports. Drawings of typical details must accompany reports. Hours and credit variable.

2742. ***RESEARCH IN STRUCTURAL ENGINEERING.*** On demand. 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. Hours and credit variable.

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. 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. Hours and credit variable.

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

Messrs. Blessis, Gebhard, Richards, and staff.

2901. ***CONSTRUCTION METHODS.*** Credit 3 hrs. Fall-spring. 3 Rec. Introduction to methods, equipment, and management principles and procedures involved in construction activities; nature of the construction industry and sources of information concerning it; problems and oral reports by students based on current literature; correlation of money, men, materials, machines, and design details to produce economic results. Mr. Richards.

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, forms of business organizations, sales, insurance, utilities, labor, government regulation of business, sales, negotiable instruments, workmen's compensation, liens, bankruptcy, patents, copyrights, trademarks; work of the expert witness; ethical responsibilities; professional registration; special emphasis on contract documents used in construction work.

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.* Credit 3 hrs. On demand. 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. Mr. GEBHARD.

2906. *ADVANCED ENGINEERING LAW.* Credit 3 hrs. On demand. 3 Rec. Prereq., 2902. An extension by the use of case material of the legal principles and practices covered in 2902, particularly those which apply to construction contracts, and employer-employee relationships. Mr. RICHARDS.

2907. *CONSTRUCTION MANAGEMENT.* Credit 3 hrs. On demand. 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. Mr. GEBHARD.

2941. *PROJECT. CONSTRUCTION ENGINEERING AND ADMINISTRATION.* Credit 3 hrs. On demand. Prereqs., 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.* Credit 3 hrs. On demand. Prereqs., 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.* Credit 1–6 hrs. On demand. Prereqs., 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.

MECHANICAL ENGINEERING

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

GENERAL

3041. *NONRESIDENT LECTURES.* Terms 9 and 10. Required. Total credit 1 hr. for both terms. Fall and spring. 1 Lect. Given by lecturers invited from industry and from certain other departments of the University for the purpose of assisting students in their approach to employment and in their transition from college to industrial life. Under the direction of Messrs. LOBERG, WEHE.

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 member 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, Mr. Pierce.

ENGINEERING DESIGN

Messrs. ABRAHAMS, BAIRD, BOOKER, BURR, DUBOIS, FEHR, OCVIRK, PHELAN (on leave 1963–1964), SIEGFRIED, WEHE.

3052. *INDUSTRIAL ACOUSTICS.* Credit 3 hrs. Fall. 2 Lect. 1 Lab. For graduate and qualified fifth year students. Treatment from the engineering point of view. Sources of noise, their measurement, and means for reduction; attenuation of airborne and structure-borne sound; transducers; room acoustics and psychoacoustics; effect of noise on people. Application of ultrasonic waves for testing, control, and processing. Mr. FEHR.

3115. *CREATIVE SKETCHING.* Credit 2 hrs. Fall. 2 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. Mr. BAIRD.

3116. *INTRODUCTION TO INDUSTRIAL DESIGN.* Credit 3 hrs. Spring. 2 Lab. Prereq., permission. Readings; abstract and applied design problems which investigate and apply the interrelationships existing between form, function, and materials. Mr. BAIRD.

3190. *SPECIAL INVESTIGATIONS IN GRAPHICS OR INDUSTRIAL DESIGN.* Credit based upon actual hours of work. Lab. as required. Fall or spring. Also may be elected by students who desire the first term only of the Industrial Design Project. Mr. BAIRD.

3198, 3199. *INDUSTRIAL DESIGN PROJECT.* Total credit 6 hrs. Ninth and tenth terms. 2 Lab. Prereq., 3116. Project work includes readings and design problems. Readings integrate design with the contemporary social and economic scene. Design problems are directed toward creation of a comprehensive attitude in product development and toward attainment of a measure of design ability. Mr. BAIRD.

3321. *KINEMATICS AND DYNAMICS OF MECHANISMS.* Credit 4 hrs. Fall. 3 Rec. 1 Comp. Prereq., 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. Counterbalancing. Synthesis of mechanisms. Mr. OCVIRK.

[**3322. *MECHANICAL ANALYSIS AND DESIGN.*** Credit 5 hrs. Fall. 1 Lec. 2 Rec. 2 Des. Periods. Prereqs., 3321, 3421, 6312, and parallel with 3422. 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, choice of materials and treatment, and design for processing and assembly. Theory of lubrication. Stress-concentration, fatigue, residual stresses, and creep. Selected topics from advanced strength of materials, such as curved beams, plates, pressure vessels, rotors, and thermal stress. Layout design of one small but complete machine. Not offered in 1963–1964.]

[**3323. *DESIGN OF MACHINES.*** Credit 3 hrs. Spring. 1 Lec. 2 Des. Periods. Prereqs, 3322. Methods for design and the stimulation of ingenuity. Contemporary design of machines in selected fields. Enclosures, assembly, lubrication, controls, and other requirements for a machine as a whole. Feasibility studies and preliminary designs of mechanical systems. A more detailed design of one or more machines in the systems. Not offered in 1963–1964.]

[**3324. *VIBRATION AND CONTROL OF MECHANICAL SYSTEMS.*** Credit 4 hrs. Spring. 3 Rec. 1 Lab. Prereqs., 3321, 4302. 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, balancing, and hydraulic and pneumatic control circuits. Modern instruments for measuring force and motion. Not offered in 1963–1964.]

3331. *KINEMATICS AND COMPONENTS OF MACHINES.* Credit 3 hrs. Spring. 2 Rec. 1 Comp. Prereqs., 212 and 6311, or equivalents. Required of students in industrial engineering and may be elected by other qualified students not in mechanical engineering. Theory and analysis of mechanisms and components based upon considerations of motion, velocity, acceleration, material, strength, and durability. Cams, linkages, couplings, clutches, brakes, belts, chains, gears, bearings, shafts, and springs.

[**3332. *MECHANICAL SYSTEMS.*** Credit 3 hrs. Fall. 1 Lec. 1 Rec. 1 Lab.-Comp. Prereqs., 3331, 3431, and 6312, or equivalents. Required of students in industrial engineering and may be elected by other qualified students not in mechanical engineering. An introduction to problems associated with the design and experimental investigation of machines and systems of machines. Design considerations for processing and assembly. The synthesis and integration of components into machine systems. A brief treatment of vibration and control theory, followed by laboratory experiments. Use of modern instruments for measuring force and motion. Solution of problems by analog and digital computers. Not offered in 1963–1964.]

3353. *DESIGN OF MACHINE MEMBERS.* Credit 3 hrs. Fall. 2 Rec. 1 Comp. Prereqs., 1153, 1241, 3351 (prereq. or parallel). Application of mechanics, kinematics, materials, and processes to the design and selection of springs, couplings, clutches, brakes, belts, chains, gears, shafts, bearings, fastenings, and pressure vessels; stress concentration, residual stresses, theory of lubrication. Mr. BURR.

3354. *DESIGN OF MACHINES.* Credit 3 hrs. Spring. 1 Lect. 2 Des. Periods. Prereqs., 3353,

3404, 1242 (prereq. or parallel). Feasibility studies and preliminary designs of mechanical systems, including a more detailed design of one or more machines in the system. The design of castings, weldments, forgings, stampings, housings, and hydraulic systems for machines. Computations, sketches, and layout drawings as required. Mr. DuBois.

3361. *ADVANCED MACHINE ANALYSIS.* Credit 3 hrs. Fall. 3 Rec. Intended for graduate students but open to qualified fifth-year students. Prereqs., 3353 or 3341, 1155. Advanced analysis of special clutches and brakes; theory of film-lubricated bearings; theories of failure, design equations, stress concentration, and residual stresses; impact; simple and built-up cylinders subjected to pressure and rotation; high temperature problems, and shaft deflections. Mr. Burr.

3362. *MECHANICAL DESIGN OF TURBOMACHINERY.* Credit 3 hrs. Spring. 3 Rec. Intended for graduate students but open to qualified fifth-year students. Prereqs., 1154 or 3361, 3352 or 3367 (prereq. or parallel). 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 casing components: cylindrical, conical, torical shells; flat plates and diaphragms. Design of bearings, seals, gaskets, expansion members. Investigation of natural frequencies and critical speeds. Selection of materials. Attention is called to a companion course 3663. Mr. Ocvirk.

3366. *ADVANCED KINEMATICS.* Credit 3 hrs. Spring. 2 Rec. 1 Comp. Prereq. 3352. Advanced analytical and graphical treatment of velocities and accelerations. Further treatment of Coriolis' acceleration. Advanced analysis and design of cams, gears, and computing mechanisms. Synthesis of mechanism.

3367. *DESIGN PROBLEMS IN VIBRATIONS AND DYNAMICS.* Credit 3 hrs. Spring. 2 Lect. 1 Lab. Prereqs., 1155, 3352. Applications of dynamics and vibration theory to the design of machinery; vibration and shock mounting of machines with single and multidegrees of freedom, properties of isolators, damping devices, critical speeds of shafts and crankshaft systems; analog computer solutions; vibration instruments and experimental investigations. Messrs. Burr, Booker.

3372. *EXPERIMENTAL METHODS IN MACHINE DESIGN.* Credit 3 hrs. Fall. 1 Rec. 2 Lab. Prereq., 3353 or 3341. 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. Mr. Wehe.

3374. *CREATIVE DESIGN.* Credit 3 hrs. Fall. 3 Rec. Prereq., 3354 or equivalent. 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. Mr. DuBois.

3375. *AUTOMATIC MACHINERY.* Credit 3 hrs. Spring. 2 Rec. 1 Field trip. Prereq., 3351. A study of automatic and semiautomatic machinery such as dairy, canning, wire-forming, textile, machine-tool, computing, and printing equipment. Mr. Wehe.

3376. *AUTOMATIC CONTROL.* Credit 3 hrs. Spring. 2 Rec. 1 Lab. Prereqs., 1152, 1155, 4933 (prereq. or parallel). Introduction to feed back control theory with emphasis on the applications of hydraulic and pneumatic systems to the automatic control of machines and processes. The Laplace transform; open and closed-loop systems; transfer functions; stability criteria; frequency response; utilization of analog computers in the design of control systems; components of industrial controllers. Mr. Wehe or Mr. Booker.

3377. *AUTOMOTIVE ENGINEERING.* Credit 3 hrs. Fall of odd years. 3 Rec. Prereq., 3353. 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. Mr. DuBois.

3380. *SEMINAR IN DESIGN OF COMPLEX SYSTEMS.* Credit 3 hrs. Spring. Two meetings of 2 hours per week to be arranged. Intended for graduate and qualified fifth-year 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. Mr. Fehr.

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. Staff.

3391. ***MACHINE DESIGN SEMINAR.*** 1 hr. credit at the end of 2 terms. A one-and-a-half hour meeting approximately every other week. Required of graduate students majoring in machine design. Discussion and study of assigned topics of importance in the field by faculty, graduate students, and outside speakers.

3398, 3399. ***PROJECT.*** Total credit 6 hrs. Work of the ninth and tenth terms in the form of projects to integrate the training in mechanical engineering when such work is done principally in the field of machine design. Staff.

MATERIALS PROCESSING

Messrs. Carpenter, Dispenza, Geer, Morgan.

3421. ***PROCESSING OF MATERIALS I.*** Credit 3 hrs. Spring. 2 Lect. 1 Lab. Abstract concept of the manufacturing process. Energy, material, environmental, and topological considerations. Physics and mechanics of chip formation, plastic deformation, friction, force relationships, thermal aspects, tool wear. Machinability of materials. Capabilities of single point, multipoint, and abrasive cutting processes. General purpose and production machine tools employed. Transfer machines, automation, numerical control of machine tools. Economics of cutting. Nonchip removal processes; electrical, electrochemical, chemical, ultrasonic, electron beam methods. Basic concepts of metrology and gaging, principles of mechanical, electrical, optical, pneumatic, and radiation measuring instruments. Mr. Geer.

[**3422.** ***PROCESSING OF MATERIALS II.*** Credit 3 hrs. Fall. 1 Lect. 2 Lab. Prereq., 3421. Material displacement, addition, and modification processes. Casting of metal and alloys; solidification, heat extraction, shrinkage, and foundry processes. Metal forming theory. Capabilities of shearing, bending, squeezing, drawing, and stretching processes. Welding theory, processes, and effects, and surface coatings. Heat treatment of steel; annealing, hardening, tempering, surface treatments. Processing of nonmetallic materials; plastics molding methods. Gage laboratory and additional cutting process laboratory exercises. Mr. Geer. Not offered in 1963–1964.]

3431. ***PROCESSES OF MANUFACTURE.*** Credit 3 hrs. Fall. 1 Lect. 1 Lab. and a second lect. or lab. on alternate weeks. Physics and mechanics or chip formation, force relationships, tool wear, machinability of materials. Machine tool capabilities in single point, multipoint, and abrasive cutting processes. Economics of cutting. Nonchip material removal methods. Basic concepts of metrology and gaging, principles of measuring instruments. Casting of metal and alloys. Metal forming theory and capabilities of shearing, bending, squeezing, drawing, and stretching processes. Welding methods. Heat treatments of steel. Plastics molding. Mr. Geer.

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. Mr. Geer.

3498, 3499. ***PROJECT.*** Total credit 6 hrs. Work of the 9th and 10th terms in the form of projects to integrate the training in mechanical engineering when such work is done principally in the field of materials processing. Mr. Geer.

THERMAL ENGINEERING

Messrs. Barrows, Conta, Dropkin (on leave spring, 1964), Erdman, Fairchild, Gebhart, Mackey, McManus (on leave 1963–64), Markland (visiting professor, spring, 1964), Pierce, Shepherd.

3604. ***FLUIDS ENGINEERING II.*** Credit 3 hrs. Fall. 2 Rec. 1 Lab. Prereq., 3603. Dimensional analysis; flow over immersed bodies; boundary layer solutions; lift and drag; oblique shocks; waves in compressible flow; energy transfer between a fluid and a rotor; characteristics of turbomachines for incompressible and compressible flow; reaction and efficiency; cavitation and surging; propulsion analysis; turbojet, ram jet and rocket; hydrodynamic transmissions. Messrs. Shepherd, Pierce.

3605. ***HEAT TRANSFER.*** Credit 3 hrs. Fall. 2 Rec. 1 Lab. Prereqs., 3603, 1155. Introduction to heat transfer by conduction, convection, and radiation; steady state, transient state; steady periodic state; heat transfer in engineering apparatus; numerical methods; electrical and fluid analogues. Laboratory instruction in temperature measurement, determination of

surface coefficients, radiant energy exchange, and experimental use of analogues. Mr. DROPKIN.

3606. *THERMAL ENGINEERING LABORATORY.* Credit 3 hrs. Spring. 1 Lect. 1 Lab. Prereqs., 3602, 3604, 3605. Methods of testing; experimental determination of performance characteristics of engines, turbines, steam generating units, pumps, compressors, fans, refrigerating systems, air conditioning apparatus, auxiliaries and components of complete plants; analysis of experimental data; preparation of engineering reports. Mr. ERDMAN.

3607. *COMBUSTION ENGINES.* Credit 3 hrs. Fall-spring. 3 Rec. Prereq., accompanied or preceded by 3606. Introduction to combustion engines with emphasis on application of thermodynamics, fluid dynamics, and heat transfer; reciprocating combustion engines; gas turbines; compound engines; reaction engines. Mr. FAIRCHILD.

3608. *THERMAL POWER PLANTS.* Credit 3 hrs. Fall and spring. 3 Rec. Prereq., accompanied or preceded by 3606. Introduction to steam and binary vapor power plants with emphasis on applications of thermodynamics, fluid dynamics, and heat transfer; nuclear power. Mr. ERDMAN.

3609. *REFRIGERATION AND AIR CONDITIONING.* Credit 3 hrs. Fall-spring. 3 Rec. Prereq., accompanied or preceded by 3606. Introduction to refrigeration and air conditioning with emphasis on applications of thermodynamics, fluid dynamics, and heat transfer; compression, absorption, and other systems of refrigeration; control of the physical environment. Mr. MACKEY.

3621. *THERMAL SCIENCE I: THERMODYNAMICS.* Credit 3 hrs. Fall. 1 Lec. 2 Rec. Prereqs., Mathematics 294, Physics 224, Chemistry 276. Concept of temperature. Properties of a pure substance. First law of thermodynamics; quasistatic processes; control volume analysis; steady flow. Second law of thermodynamics; heat engines; heat pumps; Carnot principle; entropy; availability, irreversibility; Gibbs and Helmholtz free energy functions; entropy production and flow; introduction to thermodynamics of irreversible processes and thermoelectricity. Combined first and second laws; Maxwell relations; applications to systems and control volumes. Mr. CONTA.

3622. *THERMAL SCIENCE II: THERMODYNAMICS.* Credit 3 hrs. Spring. 1 Lec. 2 Rec. Prereq., 3621. Nonreacting gaseous mixtures; Dalton-Gibbs law; Amagat-Leduc law; mixtures including psychrometrics; air-conditioning processes. Nonflow and steady-flow vapor cycles; binary vapor cycles. Heat pump cycles; refrigeration cycles. Air standard nonflow and steady-flow heat engine cycles. Internal combustion engine and gas turbine processes. Thermodynamics of reacting systems; chemical equilibrium; standard state; heats of reaction, formation, and combustion; chemical potential; equilibrium constants; fugacity and activity; combustion processes. Mr. CONTA.

3623. *THERMAL SCIENCE III: FLUID MECHANICS.* Credit 3 hrs. Spring. 3 Rec. Prereqs., Mechanics 212, 3621. Hydrostatics; kinematics and dynamics of flow including introduction to hydrodynamics; Laplace equation; momentum and energy relations; Euler equations; thermodynamics of flow; wave motion; Mach number; stagnation values. Real flow phenomena; laminar and turbulent motion; pipe flow; universal velocity distribution. Compressible flow with area change; normal shock; nozzle flow. Mr. SHEPHERD.

[**3624. *THERMAL SCIENCE IV: FLUID MECHANICS.*** Credit 3 hrs. Fall. 2 Rec. 1 Lab. Prereq., 3623. Continuation of compressible flow, with friction and heating. Hydraulic analogy; flow metering; dimensional analysis. Flow over immersed bodies. Boundary layer: laminar and turbulent; exact and momentum methods of solution. Lift and drag (subsonic and supersonic). Elements of turbomachinery: Euler turbine equation; reaction; efficiency. Types of turbomachinery and turbomachine characteristics. Propulsion: forces on ducts; propulsive efficiency; elementary characteristics of thermal jets and rockets. Turbomachine components of couplings and torque converters. Not offered in 1963–1964.]

[**3625. *THERMAL SCIENCE V: HEAT TRANSFER.*** Credit 4 hrs. Fall. 1 Lec. 2 Rec. 1 Lab. Prereqs., 3622, 3623. Conduction: steady state; unsteady state with transient and periodic heat flow Analogue and relaxation methods. Convection: boundary layer fundamentals; natural convection; forced convection inside tubes and ducts; forced convection over various surfaces. Radiation: emission, absorption, reflection, transmission, and exchanges. Radiation combined with conduction and convection. Heat exchangers: over-all heat transfer coefficients; mean temperature difference; effectiveness; design. Not offered in 1963–1964.]

[**3626. *THERMAL SYSTEMS ENGINEERING.*** Credit 5 hrs. Spring. 3 Lec. 1 Lab. Prereqs., 3622, 3624, 3625. Applications of thermodynamics, fluid mechanics, and heat transfer to complete thermal systems rather than to processes. Work-producing, heat-pro-

ducing, 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. Not offered in 1963–1964.]

3630. *ENGINEERING THERMODYNAMICS.* Credit 3 hrs. 3 Rec. Laws of thermodynamics; energy equations; thermodynamic properties of state of gases and vapors, nonflow and flow processes; gas and vapor cycles; refrigeration; steam turbines. Mr. FAIRCHILD.

[**3631. *ENGINEERING FLUID MECHANICS.*** Credit 3 hrs. 3 Rec. Prereqs., Mechanics 212, 3630. Brief treatment of hydrostatics, kinetics and dynamics of flow; momentum and energy relations. Thermodynamics of flow; wave motion; stagnation properties. Real flow phenomena, laminar and turbulent motion. Pipe flow; compressible flow with area change, normal shock; nozzle flow. Dimensional analysis. Flow metering. Flow over immersed bodies; boundary layer; lift and drag. Elements of turbomachinery; turbomachine characteristics; turbomachine components in couplings and torque converters. Not offered in 1963–1964.]

[**3632. *ENGINEERING HEAT TRANSFER.*** Credit 3 hrs. 3 Rec. Prereqs., 3630, 3631. Steady one-dimensional heat conduction; systems with heat sources; two- and three-dimensional heat conduction; numerical and analogic methods. Unsteady state conduction; periodic heat flow, transient heat flow. Convection: boundary layer fundamentals; dimensional analysis. Natural convection. Forced convection inside tubes and ducts; over exterior surfaces of cylinders and spheres. Heat transfer with change of phase: boiling, condensation. Radiation: fundamentals; heat exchanges. Heat transfer by combined modes. Heat exchangers: over-all coefficients of heat transfer; mean temperature difference; design. Not offered in 1963–1964.]

3633. *ENGINEERING THERMODYNAMICS AND HEAT TRANSFER.* Credit 3 hrs. Fall. 3 Rec. Required of students in the School of Civil Engineering. Laws of thermodynamics; energy equations; thermodynamic properties of state of gases and vapors; processes; gas and vapor cycles of heat engines and heat pumps; introduction to heat transfer by conduction, convection, and radiation; heat transfer in engineering equipment by combined modes.

3642. *HEAT-POWER.* Credit 2 hrs. Spring. 2 Lect. Required of students in the School of Civil Engineering. Prereq., 3630. Vapor cycles; heat transfer; the elementary steam power plant; compressors; internal combustion engines; air conditioning MR. FAIRCHILD.

3651. *GRAPHICAL AND NUMERICAL METHODS.* Credit 3 hrs. Spring. 3 Rec. Intended for undergraduates but open to graduate students. Design of slide rules, network charts, and alignment charts; graphical and numerical methods of solution of problems in thermal engineering; fitting empirical equations to experimental data; analysis of errors. Mr. MACKEY.

[**3652. *COMBUSTION THEORY.*** Credit 3 hrs. Spring. 3 Lect. Prereq., 3605. Intended for graduate students and qualified fifth year students. Application of the basic equations of fluid flow and heat and mass transfer to homogeneous and diffusion flames. Ignition, quenching, rate processes, and dissociation effects will be examined. Consideration will be given to flame stabilization and practical systems. Mr. MCMANUS. Not offered in 1963–1964.]

3661. *ADVANCED THERMODYNAMICS.* Credit 3 hrs. Fall. 3 Rec. Intended for graduate students but open to qualified fifth year students. Prereq., 3601, 3602, or equivalent. A rigorous and general treatment of the laws of thermodynamics with emphasis on mathematical development and philosophical interpretations; the pure substance; homogeneous and heterogeneous systems; Gibbs and Helmholtz functions; Maxwell relations; availability and irreversibility; equilibrium. Mr. CONTA.

3663. *ADVANCED TURBOMACHINERY.* Credit 3 hrs. Fall. 3 Rec. Open to graduate students and qualified fifth year students. Prereqs., 3602, 3604 or equivalent. Aero- and thermodynamic design of turbomachines. Analysis of flow in impellers and blade passages. Review of analytic methods and use of cascade data. The treatment is general as far as possible, but is applied specifically to fans, compressors and pumps and to steam, gas and hydraulic turbines. A major part of the course is the aero-thermodynamic design of a high performance compressor-turbine combination. (Attention is drawn to 3362 as a companion course for mechanical design.) MR. SHEPHERD.

3664. *INTERMEDIATE FLUID MECHANICS.* Credit 3 hrs. Spring. 3 Rec. Intended for graduate students and qualified undergraduate students. A more advanced treatment of several topics in 3603 and 3604. Extension of theoretical hydrodynamics, use of complex variables; waves; two-dimensional compressible flow; method of characteristics; laminar

boundary layer in compressible flow; turbulence; turbulent boundary layer in a pressure gradient. Mr. SHEPHERD.

3665. *ADVANCED HEAT TRANSFER.* Credit 3 hrs. Fall. 3 Rec. Prereq., 3605 or consent of instructor. Basic modes of heat transfer are considered from an analytic point of view. Analytic results are compared with experimental correlations. Solutions of representative heat conduction problems, a general method of analysis for diffuse radiation, boundary layer convection solutions, similarity theory in turbulent flow, transport in rarefied gases, and an introduction to numerical methods. Mr. GEBHART.

3666. *ADVANCED AIR CONDITIONING.* Credit 3 hrs. Fall. 3 Rec. Selected studies of air conditioning principles and air conditioning apparatus; solar loads and solar collectors; heat pumps; air conditioning in transportation; thermoelectric refrigeration. Mr. MACKEY.

3667. *TEMPERATURE MEASURING INSTRUMENTS.* Credit 3 hrs. Spring. 2 Lect. 1 Lab. Intended for graduate students but open to qualified undergraduates. Prereq., 3605. Theory, construction, calibration, and application of liquid-in-glass thermometers, solid expansion thermometers, pressure-spring thermometers, resistance thermometers, thermoelectric thermometers, optical pyrometers, radiation pyrometers. Mr. DROPKIN.

3670. *ADVANCED COMBUSTION ENGINES.* Credit 3 hrs. Spring. 3 Rec. Intended for graduate students but open to qualified undergraduates. Prereqs., 3604, 3607 or equivalent. Advanced study of topics in field of reciprocating engines, both spark-ignition and diesel. Methods of thermodynamic analysis and performance prediction for free-piston power plants and supercharged engines. Relation of engine performance characteristics and performance characteristics of automotive vehicles. Recommended together with Course 3377 for study in automotive engineering. Mr. FAIRCHILD.

3671. *AEROSPACE PROPULSION SYSTEMS.* Credit 3 hrs. Spring. 3 Rec. Prereqs., 3603, 3604, 3607 or equivalent. Intended for graduate students and qualified fifth year students. Application of thermodynamics and fluid mechanics to the design and performance of thermal-jet and rocket engines in the atmosphere and in space. Mission analysis in space as it affects the propulsion system. Consideration of auxiliary power supply; study of advanced methods of space propulsion. Mr. SHEPHERD.

3672. *ENERGY CONVERSION.* Credit 3 hrs. Spring. 3 Lect. Intended for graduate students but open to qualified fifth year students. Prereqs., 3601, 3602, 3603, 3604, or equivalent. Primarily a classification and thermodynamic analysis of energy conversion devices, but energy sources and the storage of energy are also considered. A study of conventional heat engines and combustion engines; thermo-electric, thermionic, photovoltaic, and magneto-hydrodynamic generators; and fuel cells. Materials, design, and application to conventional and space power requirements are also considered. Mr. CONTA.

[**3673. *ADVANCED THERMAL ENGINEERING MEASUREMENTS.*** Credit 3 hrs. Fall. 2 Lectures. 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. Mr. MCMANUS. Not offered in 1963–1964.]

3674. *MICROSCOPIC THERMODYNAMICS.* Credit 3 hrs. Fall. 3 Rec. Intended for graduate and qualified fifth year students. Fundamental equations of kinetic theory. Maxwell-Boltzmann statistics and quantum statistics are derived and used to interpret the phenomenological transport and thermodynamic properties of ideal, inert, and reacting gaseous systems. Consideration given to real gases. Computer knowledge desirable. Mr. PIERCE.

3680. *ADVANCED CONVECTION HEAT TRANSFER.* Credit 3 hrs. Fall. 3 Rec. Prereq., 3605 or consent of instructor. Processes of transport of thermal energy, momentum, and mass in fluids are considered in detail. Theories of transfer processes and analytic solutions. Analytical and experimental results compared. Transport equations for a fluid, delineation of kinds of processes, differential similarity, natural convection, forced convection at low and high velocities. Boundary layer solutions, similarity theories, and effects of turbulence. Transport in rarefied gases. Mr. GEBHART.

3681. *ADVANCED CONDUCTION AND RADIATION HEAT TRANSFER.* Credit 3 hrs. Spring. 3 Rec. Prereq., 3605 or consent of instructor. Theories of conduction mechanisms. The conduction of heat in solids under conditions of steady, unsteady, and periodic heat flow with and without internal sources. Mathematical, numerical, and analogue methods of problem solution are considered. The various types of thermal radiation processes in solids

and gases. Spatial and specular distribution of radiation. Methods of calculation for radiation in the absence and in the presence of absorbing and emitting gases. Mr. GEBHART.

3682. ***SEMINAR IN HEAT TRANSFER.*** Credit 3 hrs. Spring. Two meetings of 2 hours per week to be arranged. Prereq., permission of professor in charge. Discussion of fields of active inquiry and current interest in heat transfer. Considerations of major recent work and several summaries of associated contributions. Mr GEBHART.

3683. ***VISCOUS FLOW THEORY.*** Credit 3 hrs. Fall. 3 Rec. Prereq., permission of instructor. Intended for graduate students but open to qualified fifth year students with consent of instructor. Stress and rates of deformation tensors; dissipation function, derivation of the Navier-Stokes equations. Exact solutions, very slow motion, boundary layers, jets and wakes, hydrodynamic stability, turbulence. Mr. BARROWS.

3690. ***SPECIAL INVESIGATIONS IN THERMAL ENGINEERING.*** Spring. Credit to depend upon hours of actual work. Informal instruction will be given to a limited number of students interested in work to supplement that given in courses in combustion engines, power generation, fluid dynamics, heat transfer, refrigeration, air conditioning, and instruments. Permission of the Department necessary for registration Mr. SHEPHERD.

3691. ***THERMAL ENGINEERING SEMINAR.*** No credit. A one-and-a-half-hour meeting approximately every other week. Attendance expected of all graduate students with major subject in the Department of Thermal Engineering. Talks by graduate students, staff members, and invited guests.

3698, 3699. ***PROJECT.*** Total credit 6 hrs. Work of the ninth and tenth terms to integrate the training in mechanical engineering, principally in the fields of thermodynamics, fluid dynamics, heat transfer, combustion engines, energy conversion, power plants, refrigeration, and air conditioning. Staff.

ELECTRICAL ENGINEERING

REQUIRED COURSES

4021. ***TECHNICAL WRITING AND PRESENTATION.*** Credit 3 hrs. Fall. 3 Lect.-Rec. The development of the basic principles of exposition, the knowledge of suitable form, and the appreciation of function that will enable students to write and present reports and communications that meet professional standards.

4041. ***NONRESIDENT LECTURES.*** Credit 1 hr. Fall. 1 Lect. Given by lecturers invited from industry and from certain other departments of the University to assist students in their approach to employment and in their transition from college to industrial life.

4113. ***TRANSMISSION LINES AND WAVES.*** Credit 3 hrs. Fall. 2 Lect. 1 Comp. Prereq., 4112. Strip transmission line, one-dimensional electromagnetic waves; mechanical waves; transients, reflections; sinusoidal wave functions, impedance; four-terminal networks, resonators, filters; three-dimensional waves, oblique reflection; rectangular waveguide.

4122. ***ELEMENTS OF SYSTEM THEORY.*** Credit 4 hrs. Fall. 2 Lect. 1 Rec. 1 Lab. Prereqs., 4121 and 4114 or their equivalent. Elementary signals for system analysis; model making of system devices (tubes, transistors, transducers, sensors) with lumped parameters; matrix analysis of interconnected linear models; flow-graphs and analysis by analog simulation; stability; physical realizability and realization techniques; feedback control; system parameter-sensitivity; design methods for compensation; approximations in the frequency and time domains; signal generation; system optimization for deterministic signals.

4123. ***ELECTRONICS OF SIGNAL TRANSMISSION.*** Credit 4 hrs. Spring. 2 Lect. 1 Rec. 1 Lab. Prereq., 4122. Information content of messages and the role of band-width and noise in signal transmission; sampling theory; auto-correlation and cross-correlation techniques in signal analysis and detection; modulation theory and techniques; probability theory applied to signals; noise calculations in networks and amplifiers; laboratory work on measurements, wave shaping, modulation circuits, feedback, and oscillation.

4165. ***INTRODUCTION TO ELECTROMAGNETIC THEORY.*** Credit 4 hrs. Spring. 3 Lect. 1 Comp. Prereqs., 2331 and 4113. The foundations of electromagnetic theory and its applications to electrical engineering; vector analysis, including vector calculus; electric, magnetic, and electromagnetic fields, Maxwell's equations; applications include circuits, generators, simple magnetohydrodynamic devices, wave guides, elementary antennas, simple traveling-wave tubes.

4221. ***ALTERNATING CURRENT MACHINERY.*** Credit 4 hrs. Fall. 1 Conf. 1 Comp. Prereqs., 4112, 4216. Theory, construction, and operating characteristics of transformers, induction motors, synchronous machines, and single-phase motors.

4226. ***ELECTRICAL MACHINERY LABORATORY.*** Credit 4 hrs. Spring. 1 Lect. 1 Rec. 1 Lab. Prereq., 4221. Magnetization and circuits with nonsinusoidal voltages. Harmonics in polyphase systems; instrument, constant current, and constant potential transformers; single-phase and polyphase induction motors; synchronous machines.

SYSTEMS SEQUENCE

4301. ***LINEAR PASSIVE NETWORKS.*** Credit 3 hrs. Fall. 2 Lect. 1 Rec.-Comp. Prereq., Electrical Science 242 or 244 or equivalent. Analysis of RLC networks with exponential excitations; emphasis on the sinusoidal steady state; orderly and exact procedures for solving complex linear network problems stressing understanding of the physical significance of all solutions; matrix methods; limitations of physical networks; synthesis of periodic signals by Fourier series.

4302. ***INTRODUCTION TO ACTIVE SYSTEMS.*** Credit 3 hrs. Spring. 2 Lect. 1 Rec.-Comp. Prereq., 4301. Analysis and design of systems with linear and nonlinear, passive and active elements; analytical and graphical techniques. Amplifiers, oscillators, electromechanical transducers and modulators; equivalent circuits; concepts of energy balance; feedback and stability; application to instrumentation, control, electromechanical energy conversion, and communication.

[**4401.** ***LINEAR SYSTEMS ANALYSIS.*** Credit 4 hrs. Fall. 3 Lect. 1 Rec.-Comp. Prereq., 4301. Analysis of linear systems subjected to arbitrary excitations. Fourier, double-sided Laplace, and z-transforms by contour integration in the complex plane; frequency-domain analysis by transforms; time-domain analysis by the convolution integral; relationship of time- and frequency-domain analyses, s-plane transformations; singularity functions applied to signal synthesis and the representation of initial conditions. Not to be offered until 1964-1965.]

[**4402.** ***ACTIVE SYSTEMS.*** Credit 4 hrs. Spring. 3 Lect. 1 Rec. Prereqs., 4302 and 4401. Analysis of systems containing passive elements and controlled sources. Formal methods; matrix analysis of interconnected linear models; flow graphs and analog simulation; methods for determining stability; system-parameter sensitivity and feedback; signal generation; filter synthesis; compensating networks; physical realizability; linear time-variable networks. Emphasis on the physical and mathematical understanding required to achieve desired system behavior. Not to be offered until 1964–1965.]

[**4501.** ***SYSTEMS WITH RANDOM SIGNALS.*** Credit 4 hrs. Spring. 3 Lect. 1 Rec. Prereq., 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. Not to be offered until 1965–1966.]

[**4502.** ***STATISTICAL ASPECTS OF SYSTEM ANALYSIS.*** Credit 4 hours. Fall. 3 Lect. 1 Rec. Prereq., 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. Not to be offered until 1965–1966.]

ELECTROPHYSICS SEQUENCE

4311. ***ELECTROMAGNETIC WAVES.*** Credit 4 hrs. Fall. 3 Lect. 1 Rec.-Comp. Prereqs., Electrical Science 242 or 244 and Math 294. Foundations of electromagnetic theory for propagation and radiation of electromagnetic waves; Maxwell's equation; transmission lines, one-dimensional waves; plane waves; oblique reflection; guided waves, strip-line and rectangular wave guide; radiation; elementary antenna concepts.

4312. ***APPLIED THERMODYNAMICS.*** Credit 4 hrs. Spring. 3 Lect. 1 Rec.-Comp. Prereqs., Chem 276, Physics 224. Brief review and applications of general laws of thermodynamics to gases. Elements of one-dimensional compressible-gas dynamics, channel flows, shock waves, and applications in flow systems; elements of kinetic theory, a derivation of the Navier-Stokes equations and Boltzmann's equation; quantum statistics applied to heat capacities, chemical reactions, and ionized gases; basic formulation of fluid plasma equations and waves in the plasma.

[**4411.** ***QUANTUM THEORY.*** Credit 4 hrs. Fall. 3 Lect. 1 Rec.-Comp. Prereq., 4312. Introduction to nonrelativistic 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. Not to be offered until 1964–1965.]

[**4412.** ***SOLID-STATE PHYSICS.*** Credit 4 hrs. Fall. 3 Lect. 1 Rec.-Comp. Prereq., 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. Not to be offered until 1964–1965.]

[**4511.** ***ELECTRODYNAMICS.*** Credit 4 hrs. Fall. 3 Lect. 1 Rec. Prereqs., 4312, 4402. Static fields; electromagnetic stresses, forces and torques; quasi-stationary fields, eddy currents; electromechanical energy conversion; traveling waves generated by distributed currents; transformation to moving reference frames, unipolar induction; interaction of fields with rigid and fluid conductors in motion; interaction of fields with charged particles and plasmas; transport processes in plasmas. Not to be offered until 1965–1966.]

[**4512.** ***FIELDS, WAVES AND ELECTRONS.*** Credit 4 hrs. Spring. 3 Lect. 1 Rec. Prereqs., 4412, 4511. Electromagnetic fields and waves in metal and dielectric wave guides and cavities; plasma and electron-beam generation; fields and waves in stationary and moving plasmas, coupling of modes of wave propagation; sources of electronic noise. Not to be offered until 1965–1966.]

LABORATORY SEQUENCE

4321. ***ELECTRICAL LABORATORY I.*** Credit 4 hrs. Fall. 1 Lect. 2 Labs. 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 Labs. 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 Labs. 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. Not to be offered until 1964–1965.]

[**4422.** ***ELECTRICAL LABORATORY IV.*** Credit 4 hrs. Spring. 1 Lect. 2 Labs. 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. Not to be offered until 1964–1965.]

HONORS PROGRAM

[**4403.** ***SYSTEMS ANALYSIS.*** Credit 4 hrs. 3 Lect. 1 Rec.-Comp. Prereqs., 4302, and Math 422. (Intended for students in the Pre-graduate Honors Program.) Application of mathematical concepts to the analysis of linear systems subjected to arbitrary excitations. Analysis of systems containing passive elements and controlled sources; flow graphs, feedback and stability, methods for determining system stability, signal generation and analysis of linear and nonlinear oscillators. Physical realizability, linear time varying networks. Applications of the formal analysis techniques to systems of practical importance will be presented in the recitation-computing sections. Not to be offered until 1964–1965.]

[**4404.** ***PROBABILITY THEORY AND SYSTEM APPLICATIONS.*** Credit 4 hrs. 4 Lect. Prereq., 4403. (Intended for students in the Pre-graduate Honors Program.) Mathematical development of probability theory with applications to random processes in linear systems. Basic rules of probability; sets; combinational analysis. Random variables; expected values; characteristic functions. Statistical averages; law of large numbers. Random processes; correlation functions; power spectral densities. Linear system analysis with random input; input-output relations; Gaussian processes in linear systems. Selected topics in the statistical aspects of system analysis. Individual preparation and seminar presentation of selected topics will be encouraged. Not to be offered until 1964–1965.]

[**4414.** ***ELECTROPHYSICS HONORS SEMINAR.*** Credit 4 hrs. Spring. Prereqs., Math 423, 4411. (Intended for students in the Pre-graduate Honors Program.) Electromagnetic fields and forces, electromechanics; traveling electromagnetic waves, waveguides, cavities; maintenance, diagnosis of plasmas, electromagnetic fields and waves in stationary and drifting plasmas; thermal and quantum sources

of electronic noise. Individual preparation and seminar presentation of selected topics. Not to be offered until 1964–1965.]

ELECTIVE AND GRADUATE COURSES

GENERAL

4090. ***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.

4091 and 4092. ***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.

4095. ***INTRODUCTION TO RANDOM PROCESSES.*** Credit 3 hrs. Fall. 3 Lect. Prereq., 4123 or consent of instructor. Mathematical development of probability theory and the theory of random processes in linear systems. Sets and measure, axioms of probability. Random variables, distributions, expectations and moments, characteristic functions, laws of large numbers, the central limit theorem. Statistical description of random process, stationarity, correlation functions, spectral densities, Gaussian random processes. Input-output relations for linear systems with random excitations. Orthogonal representation of signals, the sampling theorem.

POWER SYSTEMS AND MACHINERY

4325. ***ELECTRICAL MACHINE THEORY.*** Credit 3 hrs. Fall. (Offered only if demand is sufficient.) 1 Conf. 1 Comp. Prereq., 4226. Space harmonics; parasitic torques; two-reaction analysis; transient impedances; symmetrical component impedances; single-phase motor analysis; commutator-type a-c machines.

4326. ***ELECTRICAL MACHINERY LABORATORY.*** Credit 3 hrs. Spring. (Offered only if demand is sufficient.) 1 Lect. 1 Lab. Prereq., 4321. Salient-pole synchronous machines; induction motor loss separation; energy metering; special topics.

4351. ***UNIFIED THEORY OF ELECTROMECHANICAL SYSTEMS.*** Credit 3 hrs. Fall. 2 Lect.-Rec. 1 Lab.-Comp. Prereqs., 4114, 4221 or equivalent. Electric machines studied as networks of coupled circuits with periodically varying parameters; matrix analysis of networks; forces and torques in electromechanical systems; electromagnetic and electrostatic transducers; single-phase a-c generators; 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; laboratory exercises using the generalized machine.

4541. ***APPLIED ACOUSTICS.*** Credit 3 hrs. Fall. 2 Lect.-Rec. 1 Lab. Lab assignments to meet individual needs. Prereq., 4123. The laws of ideal gases, the thermodynamic properties of air, and the laws of the propagation of compressional waves; the transmission of sound through tubes, horns, and unbounded media; the design of sound sources, microphones, loudspeakers, and wax, lacquer, magnetic, and photographic recorders; reflection, absorption, and reverberation.

4551. ***RADIO AIDS TO NAVIGATION.*** Credit 2 hrs. Spring. 2 Lect.-Rec. Prereq., 4123. Long-wave and medium-wave direction finders and radio beacons; atmospheric effects and limitations on accuracy; medium-frequency pulsed transit-time systems and high-frequency return-signal systems, with application to long-range navigation and precision mapping; airport approach systems and traffic control.

ELECTRONICS AND MICRO WAVES

4521. ***MICROWAVE LABORATORY.*** Either term. Credit 1–3 hrs. At least 2 lab. for 3 hrs. credit. Prereq., either 4527 or 4561 must precede or be taken concurrently. A wide variety of experiments is available in the area of measurement of active and passive microwave devices, including klystrons, traveling wave tubes, magnetrons, cavities, microwave components, and periodic structures. The experiments are designed to encourage the exploration of the device characteristics while simultaneously developing measurement techniques which range in character from standard techniques to those of considerable sophistication. In addition to performing several of the available experiments the student will design and execute some laboratory project of interest to him. Stress is laid on independent work by the student.

4526. ***ELECTRON DYNAMICS.*** Credit 3 hrs. Fall. 2 Lect. 1 Lab. Prereqs., Physics 314, and 4122. Fundamental theory of low-frequency electron devices; emission; conformal mapping; particle dynamics; electrostatic and magnetic lenses; space charge phenomena; limitations at high frequencies; noise; thermoelectric conversion; motion of electrons and holes in

metals and semiconductors; junction diodes and transistors.

4527. *MICROWAVE ELECTRONICS I.* Credit 3 hrs. Spring. 3 Lect. Coreqs., 4526 and 4565 or consent of the instructor. Study of the theory of the interaction of electron streams and electromagnetic waves in localized and distributed regions; the electron-ballistic and the space-charge-wave approaches; application to planar vacuum tubes and microwave tubes. It is suggested that 4521 be taken concurrently.

4528. *MICROWAVE ELECTRONICS II.* Credit 3 hrs. Fall. 3 Lect. Prereqs., 4527 and 4561. Topics will be discussed drawn from these areas: propagation of electromagnetic waves in periodic structures, anisotropic media, and plasmas; theory of the interaction between electron beams and microwave circuits including linear and nonlinear effects; noise in microwave devices.

4352. *ELEMENTS OF POWER-SYSTEM ANALYSIS.* Credit 3 hrs. Fall. 2 Lect.-Rec. 1 Lab.-Comp. Prereqs., 4113, 4226 or equivalent. Studies of power systems through the application of equivalent circuits of synchronous machines, transmission lines, transformers and static loads; power-system network theory; power angle equations and circle diagrams; the two-machine system; load flow and voltage regulation of complex systems; symmetrical components; fault analysis of complex systems; introduction to system stability; use of a-c and d-c network analyzers as computing aids.

4353. *TRANSIENT ANALYSIS OF POWER SYSTEMS.* Credit 3 hrs. Spring. 2 Lect.-Rec. 1 Lab.-Comp. Prereqs., 4351, 4352 or equivalent. Study of synchronizing and damping torques for salient-pole and solid-rotor machines; application of constant-flux-linkage theorem to balanced and unbalanced faults; basic assumptions for transient stability studies; voltage regulators and governors; control of system frequency; application of a-c network analyzers and digital computers to transient problems; theory of the electric arc; a-c arc interrupting media; simulated testing of circuit breakers.

4371. *HIGH-VOLTAGE PHENOMENA.* Credit 3 hrs. Spring. 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.

RADIO AND COMMUNICATION

4501. *RADIO AND COMMUNICATION SEMINAR.* Credit 1 to 3 hrs. Fall and spring. Primarily for graduate students. Reading and discussion of technical papers and publications in the field of radio and communication.

4511. *PHYSICAL BASIS OF ELECTRONIC ENGINEERING.* Credit 3 hrs. Fall. 3 Lect. Prereqs., 4113, 4121, Physics 314. The control and use of electrons in modern electronic engineering. The underlying physical phenomena of electronic devices treated in depth, including power exchanges, noise generation, nonlinearity and frequency band-width limitations, conventional, microwave, and quantum electronic principles.

4512. *FIELDS, WAVES AND ELECTRONS.* Credit 4 hrs. Spring. 3 Lect. 1 Rec. Prereqs., 4412, 4511. Electromagnetic fields and waves in metal and dielectric wave guides and cavities; plasma and electron-beam generation; fields and waves in stationary and moving plasmas, coupling of modes of wave propagation; sources of electronic noise.

4516, 4517. *RADIO AND COMMUNICATION LABORATORY.* Credit 3 hrs. each. Fall and spring respectively. Either or both may be taken. (Offered only if demand is sufficient.) 1 Rec. 1 Lab. Prereqs., 4113 and 4123. Choice of three to five different experiments from the field of electronic circuits, networks, transmission lines; wave guides, and antennas. Experiments selected to meet individual needs.

4529. *SEMICONDUCTOR ELECTRONICS I.* Credit 3 hrs. Fall. 2 Lect. 1 Lab. Prereqs., Physics 314, and 4123. Motion of electrons and holes in semiconductors; theory of P-N junctions, metal-semiconductor contacts, and junction triodes; preparation of materials and fabrication of devices; characteristics of diodes and rectifiers, tunnel diodes, solar batteries, transistors, four-layer devices (diodes, controlled rectifiers, and switches), etc.; transistor equivalent circuits; bias-stabilized transistor amplifiers.

4530. *SEMICONDUCTOR ELECTRONICS II.* Credit 3 hrs. Spring. 2 Lect. 1 Lab. Prereq., 4529. 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 converters, amplifiers, oscillators and multivibrators, pulse circuits, gates and switches, modulators, and other circuits.

4531. *QUANTUM ELECTRONICS I.* Credit 3 hrs. Fall. 3 Lect. Prereq., Physics 325–326 or 4165 and Physics 443 or 314. A detailed

treatment of the physical principles underlying masers and lasers. Topics will include the interaction of radiation and matter; quantum properties of an electromagnetic radiation field; the coherence properties of spontaneous and stimulated emission of radiation; theory of partial coherence; thermal equilibrium and non-equilibrium in paramagnetic systems; quantum theory of angular mementum with application to atomic structure; properties of paramagnetic ions in crystals.

4532. ***QUANTUM ELECTRONICS II.*** Credit 3 hrs. Spring. 3 Lect. Prereq., Quantum Electronics I or consent of instructor. A continuation of the treatment of the physical principles underlying maser devices. Topics will include the analysis of solid state and gaseous masers and lasers including the methods used to obtain state inversion; operating characteristics of the most important of these devices; semiconductor injection lasers; nonlinear processes such as double quantum absorbtion, harmonic generation, photomixing; applications of masers and lasers.

4561. ***MICROWAVE THEORY AND TECHNIQUES.*** Credit 3 hrs. Fall. 3 Lect. Prereq., 4565 or equivalent. Theory of microwave circuits; normal modes in uniform waveguides and cavities; power and energy relations; obstacles in waveguides and inhomogeneous media; perturbational and variational techniques; periodic circuits.

4562. ***MICROWAVE ELECTRONICS SEMINAR.*** Credit variable. Spring. Fields and waves in plasmas; beam-plasma interaction; fields and waves in ferrites; millimeter waves; microwave filters; advanced beam-circuit interaction. Microwave electronics staff.

ELECTROMAGNETIC WAVES AND PROPAGATION

4566. ***INTRODUCTION TO PLASMA PHYSICS.*** Credit 3 hrs. Fall. 3 Lect. Prereqs., 2331 and 4565, or equivalent. Charged particle dynamics; continuum plasma theory; conduction of electricity in gases; magnetohydrodynamcs with applications; transverse and longitudinal waves; magneto-ionic theory with applications.

4567. ***RADIO WAVE PROPAGATION.*** Credit 3 hrs. Spring. 3 Lect. Prereq., 4565. Influence of the trophosphere on radio wave propagation; dielectric properties of air and distributions of refractive index; propagation in standard and nonstandard atmospheres; diffraction around a spherical earth; inhomogeneities of refractive index; scattering.

4568. ***ANTENNAS.*** Credit 3 hrs. Spring. 3 Lect. Prereq., 4565. Theory of radiation and reception; directional characteristics; impedance; elementary theory of cylindrical antennas; Huygens' principle; aperture antennas; antenna thermodynamics.

4581. ***MAGNETOHYDRODYNAMICAL PROCESSES IN THE SOLAR SYSTEM.*** Credit 2 hrs. Fall. 2 Lect. Prereq., 4565 or Physics 325–26. Theories of solar phenomena—solar flares, prominences, coronal features; the interplanetary plasma—density, velocity, ionization, magnetic fields; cosmic ray effects associated with solar events—production and modulation; theories of magnetic disturbances, magnetic storms, aurorae, Van Allen radiation, and associated ionospheric effects.

SYSTEM THEORY

4115. ***PRINCIPLES OF NONLINEAR SYSTEMS.*** Credit 3 hrs. Fall. 3 Lect. Prereq., 4114 or equivalent. Analysis of first and second order nonlinear systems with applications. Phase-plane analysis, static equilibrium, limit-cycles, Poincare-Bendixson Theory, Orbital stability, Geometrical analysis of periodic system behavior, bifurication. Theory of van der Pol method of averaging. Graphical construction of phase trajectories. Piecewise linear and stepwise approximations. Relaxation oscillations. Liapounov's first and second method on stability. Forced oscillations, harmonic balance. Duffing's equation, jump and hysteresis phenomena, subharmonics. Frequency entrainment. Parametric excitation and amplification.

4563. ***RANDOM PROCESSES IN COMMUNICATION SYSTEMS.*** Credit 3 hrs. Spring. 3 Lect. Prereq., 4095 or consent of instructor. 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.

4564. ***TRANSMISSION OF INFORMATION.*** Credit 3 hrs. Spring. 3 Lect. Prereq., 4095 or consent of instructor. 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.

4571. ***MODERN NETWORK ANALYSIS.*** Credit 3 hrs. Fall. 3 Lect. Prereq., 4122 or equivalent. Network topology and its relation to the analysis of complex systems; energy functions; network functions; general realizability criteria; interrelationship of network functions; Hilbert transforms; flow graphs; generalized coordinates; scattering parameters.

4572. ***MODERN NETWORK SYNTHESIS.*** Credit 3 hrs. Spring. 3 Lect. Prereq., 4571. Real-part sufficiency and related topics; the realization problem of driving-point and transfer functions. Darlington's theory; the Miyata method; Guillemin's zero-shifting technique; iterative and other "classical" procedures; the approximation problem—least square and Tschebyscheff sense—in the frequency domain; time-domain synthesis; correlation between frequency and time domains.

4575. ***ADVANCED TOPICS IN SYSTEM THEORY.*** 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 students to select needed information from available sources. For fall 1963: statistical theory of signal detection. Credit 3 hrs. Prereq., 4563, and 4564 or consent of the instructor. Description of noise. Hypothesis testing and detection of signals. Estimation of signal parameters. Detection of signals of unknown arrival time. Signal resolution.

ILLUMINATION

4611. ***INTRODUCTORY ILLUMINATION.*** Credit 3 hrs. Fall. 2 Rec. 1 Lab.-Comp. Prereq., Physics 224. Problems commonly encountered in illumination engineering and the methods of solution; sources of light; visual perception; light control, both spectral and directional; measurement of light sources and illumination; general illumination design; production and mixing of colors; architectural objectives.

4612. ***ILLUMINATING ENGINEERING.*** Credit 3 hrs. Spring. (Offered only if demand is sufficient.) 2 Rec. 1 Lab.-Comp. Prereq., 4611. Computation of light-flux distribution and study of difficult lighting problems; emphasis on specialized rather than general lighting problems.

4615. ***ILLUMINATION SEMINAR.*** Credit 2 hrs. Fall. (Offered only if demand is sufficient.) One 2-hour period each week. Must be accompanied or preceded by 4611. Reports on selected topics of current interest in illuminating engineering.

CONTROL SYSTEMS AND COMPUTERS

4711. ***FEEDBACK CONTROL SYSTEMS I.*** Credit 3 hrs. Fall. 2 Lect. 1 Lab. Prereqs., 4122, 4216, 4221. Principles of feedback control systems emphasizing analysis of performance from equations and transfer-function plots; Laplace transformations; error detecting devices; hydraulic devices; factors affecting errors, damping, and speed of response; criteria for stability.

4712. ***FEEDBACK CONTROL SYSTEMS II.*** Credit 3 hrs. Spring. 2 Lect. 1 Lab. Prereq., 4711. Synthesis of feedback control systems; prediction of performance from stability criteria and comparison with laboratory performance; relay control systems; consideration of nonlinearity.

4713. ***RANDOM PROCESSES IN CONTROL SYSTEMS.*** Credit 3 hrs. Spring. 3 Lect. Prereq., 4095 or 4712 or with consent of instructor. Optimum filtering and prediction. Limitation by fixed elements in minimization. Limitation of saturation in minimization. Design of control system for minimum bandwidth. Minimization of integral square error. Random processes in sampled data control systems. Analysis of nonstationary random processes. Series approximation of nonlinear systems. Technique using differential and integral equations for nonlinear systems. Other techniques for statistical analysis of nonlinear control systems. Minimization techniques by the method of dynamic programming.

4714. ***OPTIMIZATION TECHNIQUES IN CONTROL SYSTEMS.*** Credit 3 hrs. Spring. 3 Lect. Prereq., 4095 and either 4711 or 4571. State-space concept. Solution of matrix-differential equations, state vectors and fundamental matrix. Development of maximum principle; minimum time problem, minimum energy problem and generalized performance criteria. Development of dynamic programming; optimum design of discrete and continuous control systems via dynamic programming. Controller implementation. Effects of inaccuracies of components. Optimum design of adaptive control.

4720. ***SEMINAR IN CONTROL SYSTEMS.*** Credit 2 hrs. Fall or spring. Prereqs., 4713 and 4714. 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.

4810. ***ANALOG COMPUTATION.*** Credit 3 hrs. Fall. 2 Lect. 1 Lab. Prereq., 4121 or 4933. Concepts and principles of analog computation; scaling and programming linear, nonlinear, and time-varying systems of equations; partial differential equations; adjoint computer systems; matrix programming. Laboratory work involves solution of problems on a general-purpose computer and by permission can be devoted in part to special projects to suit the student.

4820. ***SWITCHING SYSTEMS I.*** Credit 3 hrs. Spring. 2 Lect. 1 Lab. Prereq., 4123 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.

4821. ***SWITCHING SYSTEMS II.*** Credit 3 hrs. Fall. 3 Lect. Prereq., 4820 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.

COURSES FOR OTHER ENGINEERING CURRICULA

4931. ***ELECTRICAL ENGINEERING.*** Credit 3 hrs. Fall and spring. 2 Lect. 1 Comp. Prereqs., Math. 163, 1132 or 1152. An elementary study of direct-current electric circuits; the concepts of resistance, inductance, and capacitance; magnetic circuits; single-phase and three-phase alternating-current circuits; instruments and techniques appropriate for making measurements in all such circuits.

4932. ***ELECTRICAL ENGINEERING.*** Credit 3 hrs. Fall and spring. 1 Lect. 1 Rec. 1 Lab.-Comp. Prereq., 4931. D-c generators and motors; motor starters and controllers; transformers; induction motors; synchronous machines; a-c single-phase motors; d-c and a-c selsyn units.

4933. ***ELECTRICAL ENGINEERING.*** Credit 3 hrs. Fall and spring. 1 Lect. 1 Rec. 1 Lab.-Comp. Prereq., 4932. The characteristics and applications of the various commonly used electron tubes; rectifiers; amplifiers; oscillators; electronic control and instrumentation.

4991. ***ELECTRONIC CIRCUITS.*** Credit 3 hrs. Fall. (Offered only if demand is sufficient.) 3 Lect. For graduate students majoring in an engineering field other than electrical. Alternating-current circuits; characteristics of high-vacuum tubes and transistors, small-signal and large-signal amplifiers; feedback and oscillators; modulation and demodulation; simple wave-shaping circuits.

CHEMICAL ENGINEERING

5101. ***MASS AND ENERGY BALANCES.*** Credit 3 hrs. Fall. 2 Lect. 1 Comp. Parallel, Physical Chemistry 405. Engineering problems involving material and heat balances. Flowsheet systems and balances. Total energy balances for flow systems. Messrs. Winding, Thorpe.

5102. ***EQUILIBRIA AND STAGED OPERATIONS.*** Credit 3 hrs. Spring. 2 Lect. 1 Comp. Parallel, Physical Chemistry 406. Phase equilibria and phase diagrams. The equilibrium stage; mathematical description of single and multistage operations; analytical and graphical solutions. Messrs. Winding, Thorpe.

5103, 5104. ***CHEMICAL ENGINEERING THERMODYNAMICS.*** Credit 3 hrs. Fall-spring. 3 Lect. Prereqs., Chemistry 403, 404. A study of the first and second laws with application to batch and flow processes. Physical and thermodynamic properties. Availability; free energy; chemical equilibrium. Application to gas compression; process steam; power generation; adiabatic reactors; and chemical process development. Mr. Von Berg.

5105. ***ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS.*** Credit 3 hrs. Spring. 3 Lect. Prereq., 5104 or equivalent. Primarily for graduate students. Application of the general thermodynamic method to advanced problems in chemical engineering. Evaluation, estimation, and correlation of properties. Chemical and phase equilibria. Mr. Von Berg.

5106. ***REACTION KINETICS AND REACTOR DESIGN.*** Credit 2 hrs. Fall. 2 Lect. Prereq., 5104. A study of chemical reaction kinetics and principles of reactor design for chemical processes. Mr. Von Berg.

5107. ***ADVANCED REACTION KINETICS.*** Credit 3 hrs. Spring. 3 Lect. Primarily for

graduate students. Theory and applications of chemical reaction kinetics. Mr. HARRIOTT.

5108. *COLLOIDAL AND SURFACE PHENOMENA.* Credit 3 hrs. Fall. Prereq., 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. Applications to detergency, emulsions, catalysis, lubrication, and behavior of natural products. Mr. FINN.

5161. *PHASE EQUILIBRIA.* Credit 3 hrs. Fall. 3 Lect. Prereq., physical chemistry. A discussion of the phase rule and interpretation of phase diagrams. A detailed study of the pressure-temperature-composition-relations in binary and multicomponent heterogeneous systems where several phases are of variable composition. Aqueous salt systems and metal systems will also be considered. Prediction of phase data. Mr. THORPE.

5203, 5204. *CHEMICAL PROCESSES.* Credit 2 hrs. 2 class periods. An analysis of important chemical processes and industries. Fall term, inorganic chemical processes; spring term, organic chemical processes. Mr. WIEGANDT.

5205. *ANALYSIS OF PROCESS DESIGN.* Credit 2 hrs. Fall. Primarily for graduate students. Reaction chemistry, reactor design, and physical separations for selected processes recently undergoing major changes. Mr. WIEGANDT.

5255, 5256. *MATERIALS OF CONSTRUCTION.* Credit 3 hrs. each term. 3 Lect. Prereqs., or parallel courses. Phys. Chem. 403, 404. An introductory presentation of the nature, properties, treatment, and applications of the more important metals and alloys, including extractive and physical metallurgy and behavior under service conditions. Nonmetallic materials, including refractories, cement, protective coatings, and plastics, are also discussed. Messrs. MASON, RODRIGUEZ.

5303. *ANALYSIS OF STAGE PROCESSES.* Credit 3 hrs. Fall. 2 Lect. 1 Comp. Prereqs., 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. Mr. WINDING.

5304. *INTRODUCTION TO RATE PROCESSES.* Credit 3 hrs. Spring. 2 Lect. 1 Comp. Prereq., 5303. An introduction to fluid mechanics and heat transfer. Mr. J. C. SMITH.

5305. *RATE PROCESSES AND UNIT OPERATIONS.* Credit 3 hrs. Fall. 2 Lect. 1 Comp. Prereq., 5304. Rate of mass transfer; analysis of chemical engineering systems. Extension of previous studies to cover the interrelation and transient aspects of unit operations. Mr. J. C. SMITH.

5353. *UNIT OPERATIONS LABORATORY.* Credit 3 hrs. Fall. Lect. Rec. Lab. Prereq., 5304. Typical laboratory experiments involving unit operations equipment. Messrs. HARRIOTT, FINN.

5354. *PROJECT LABORATORY.* Credit 3 hrs. Spring. Special laboratory projects involving unit operations equipment. Messrs. HARRIOTT, FINN.

5503, 5504. *CHEMICAL ENGINEERING COMPUTATIONS.* Credit 2 hrs. Fall-spring. Two class periods. Prereqs., or parallels, 5303 and 5304 or equivalent. Lectures and advanced problems in fluid flow and heat transfer; heterogeneous equilibrium; distillation; gas absorption; and extraction. A selected number of the less conventional operations are also considered. Mr. SCHEELE.

5505. *ADVANCED HEAT TRANSFER.* Credit 3 hrs. Fall. 3 Lect. Prereq., 5503–5 or equivalent. Advanced topics in heat transfer. 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. Mr. J. C. SMITH.

5506. *DIFFUSIONAL OPERATIONS.* Credit 3 hrs. Spring. 3 Lect. Primarily for graduate students. Advanced topics in diffusional operations. Molecular and turbulent diffusion in binary and multicomponent systems; film, boundary layer, and penetration-theory models of mass transfer; applications to distillation, gas absorption, liquid-liquid extraction, and other industrial operations. Mr. Scheele.

5507. *ADVANCED FLUID DYNAMICS.* Credit 3 hrs. Fall. 3 Lect. Primarily for graduate students. Advanced topics in fluid dynamics. 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. Mr. Scheele.

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. Staff.

5609. *ANALYSIS AND DESIGN OF PROCESS EQUIPMENT.* Credit 3 hrs. Fall. 3 Lect. Pre-

req., 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. Mr. J. C. SMITH.

5621. ***PROCESS EVALUATION AND DESIGN.*** Credit 5 hrs. Fall. Prereqs., 5304, 5104. Techniques and case studies in chemical process design influencing reactors and separating systems; optimization of piping and equipment; economic balance within process. Cost estimating for process units and plants. Commodity survey and chemical market research. Oral and written presentation. Mr. YORK.

5622. ***PROCESS EVALUATION AND DESIGN.*** Credit 5 hrs. Spring. Continuation of 5621. Plant location, process selection, process design, equipment design and specifications; plant layout. Cost estimates and profitability for a chemical, petroleum, or petrochemical product. Pilot plant operations, research economics, product development, technical service, and related commercial aspects. Oral and written presentation. Mr. YORK.

5741. ***PETROLEUM REFINING.*** Credit 3 hrs. Spring. 3 Lect. Prereq., 5304. A critical analysis of the processes employed in petroleum refining. Mr. WIEGANDT.

5742. ***POLYMERIC MATERIALS.*** Credit 3 hrs. Fall. 3 Lect. Polymerization reactions, manufacture and properties of synthetic resins, fibers, plastics, and rubbers. Mr. RODRIGUEZ.

5743. ***PROPERTIES OF POLYMERIC MATERIALS.*** Credit 3 hrs. Spring. Prereq., 5742. Mechanical, electrical, and optical properties of polymers. Phenomenological aspects and molecular theories of non-Newtonian flow viscoelasticity and ultimate tensile properties. Mr. RODRIGUEZ.

5745. ***ANALYSIS OF POLYMERIC PROCESSES.*** Credit 3 hrs. Fall. 3 Lect. Prereq., 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. Special emphasis on new processes and means of reducing capital and operating costs. Mr. HEDRICK.

5746. ***CASE STUDIES IN THE COMMERCIAL DEVELOPMENT OF CHEMICAL PRODUCTS.*** Credit 3 hrs. Spring. 3 Lect. Prereq., or parallel, 5622. For graduate and selected fifth year 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. Mr. HEDRICK.

5747. ***PROCESS CONTROL.*** Credit 3 hrs. Fall. 2 Lect. 1 Lab. Prereq., 5304. Frequency response and transient response of process equipment. Brief description of control instruments. Design of processes and selection of controllers for desired dynamic behavior. Mr. HARRIOTT.

5748. ***FERMENTATION ENGINEERING.*** Credit 3 hrs. Spring. 2 Lect. 1 Rec. Prereqs., or parallel courses, Chemistry 404 or 408, and any course in microbiology. An advanced discussion of fermentation as a unit process. Topics include sterilization, aeration, agitation, and continuous fermentation. Mr. FINN.

5749. ***INDUSTRIAL MICROORGANISMS.*** Credit 1 hr. Fall. 1 Lect. Prereqs., organic chemistry and physical chemistry. A brief introductory course in microbiology for students with a good background in chemistry. Mr. FINN.

5752. ***POLYMERIC MATERIALS LABORATORY.*** Credit 2 hrs. Spring. 1 Lab. Prereq., 5742. Experiments in the formation, characterization, fabrication, and testing of polymers. Mr. RODRIGUEZ.

5760. ***NUCLEAR AND REACTOR ENGINEERING.*** Credit 2 hrs. Spring. 2 Lect. Fuel processing and isotope separation, radioactive waste disposal, fuel cycles, radiation damage, biological effects and hazards, shielding, power reactors. Mr. VON BERG.

5851. ***CHEMICAL MICROSCOPY.*** Credit 3 hrs. Either term. 1 Lect. 2 Lab. Prereqs., or parallel courses, Chemistry 403, 404, or 407, 408 and Physics 123, 124 or special permission. Microscopical examination of chemical and technical materials, processes and products. Measurements, particle size determination, analyses of mixtures, crystallization, phase changes and colloidal phenomena, lens systems and photomicrography. Mr. MASON.

5853. ***MICROSCOPICAL QUALITATIVE ANALYSIS (INORGANIC).*** Credit 2 hrs. or more. Offered on demand either term. Prereq., 5851. Laboratory periods to be arranged. Laboratory practice in the analysis of inorganic substances containing the more common elements. Mr. MASON.

5859. ***ADVANCED CHEMICAL MISCROSCOPY.*** Credit 1 hr. or more. Offered on demand either term. Prereq., 5851 and special permission. Laboratory practice in special methods and special applications of chemical microscopy. Mr. MASON.

5900. ***SEMINAR.*** Credit 1 hr. Fall-spring. General chemical engineering seminar required of all graduate students majoring in the field of chemical engineering. Mr. RODRIGUEZ.

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. Mr. WINDING.

5952, 5953, 5954. ***RESEARCH PROJECT.*** Credit 3 hrs.; additional credit by special permission. Fall-spring. Prereq., 5304. Research on an original problem in chemical engineering. Staff.

5955, 5956. ***SPECIAL PROJECTS IN CHEMICAL ENGINEERING.*** Credit variable. Either term. Research or studies on special problems in chemical engineering. Staff.

MATERIALS AND METALLURGICAL ENGINEERING

6112. ***METALS TECHNOLOGY.*** Credit 2 hrs. Spring. 2 Lect. Prereq., 1243. An advanced course for students in mechanical engineering covering the mechanical and metallurgical factors affecting service behavior of metals under static and dynamic loading. Subjects covered include failure criteria, brittle fracture, creep, embrittlement, fatigue, and corrosion.

6301. ***STRUCTURE OF MATERIALS I.*** **(Old 6353)** Credit 3 hrs. Fall. 3 Lect.-Rec. 1 Lab. Prereq., concurrent registration in 6311 and 6313. Characterization of metallic and nonmetallic structures by the most useful laboratory techniques, principally optical microscopy and X-ray diffraction. Structures of materials are related to composition, thermal history and both mechanical and physical properties. Techniques of specimen preparation, principles and use of microscopes and metallographs are treated. X-ray diffraction theory and techniques are introduced and applied to determination of structure of materials. Mr. NEWKIRK.

6302. ***STRUCTURE OF MATERIALS II.*** **(Old 6354)** Credit 3 hrs. Spring. 1 Lect. 2 Labs. Prereq., 6301. A continuation of 6301 with emphasis on structural changes in specific materials resulting from particular mechanical and thermal treatments. Quantitative microscopy is treated and more advanced techniques in X-ray diffraction, micro-radiography, chemical analysis by X-ray fluorescence and dilatometry are included. Mr. NEWKIRK.

6311. ***MATERIALS SCIENCE I.*** Fall. Credit 4 hrs. Prereqs., Chemistry 276 or 285, Applied Differential Equations 1155, Physics 224, 226 or 228, Mechanics 211. 3 Lect. One 2½ hr. lab. per week as assigned. Binding of atoms. Arrangement of atoms in molecules and crystals. Diffraction and structure. Equilibrium of assemblies of matter. Rate processes involving assemblies of matter. Metastable states of matter. Elastic and plastic deformation of matter under static and dynamic stress. The laboratory work includes experiments in crystal structure by X-ray diffraction, phase equilibria using thermal analysis and quenching, microstructure of materials using microscopy, crystalline imperfections by quenching and electrical resistivity and by polarized light and etch pits, diffusion of carbon in iron by carburizing and hardness profiles and by internal friction, metastable states studied by microstructure and hardness, mechanical properties of materials by tensile testing. Messrs. RUOFF, BLAKELY, GHATE, HOWE, JEFFREY, JOHNSON, RHODIN, SCALA, TAYLOR, WEART.

6313. ***MATERIALS SCIENCE I (a).*** Fall. Credit 3 hrs. Prereqs. are the same as 6311. 3 Lect. The lecture material and staff are the same as for 6311.

6323. ***METALLURGICAL THERMODYNAMICS.*** **(Old 6403)** Credit 3 hrs. Fall. 3 Lect. A discussion of thermodynamic equilibria with emphasis upon metallic liquid and solid solutions. Topics considered include binary, ternary, and quaternary phase diagrams; thermodynamic probability and disorder in crystals; partial and integral molar properties of solutions and their applications; experimental methods used in determining thermodynamic parameters. Mr. LI.

6324. ***METALLURGICAL THERMODYNAMICS.*** **(Old 6404)** Credit 3 hrs. Spring. 3 Lect. Topics considered include the equilibrium constant, the partition function, phase field boundaries in heterogeneous systems, chemical stability of ceramic materials, mastastable phases, zone purification, vacuum metallurgy, reactive atmospheres, order-disorder phenomena in alloys, surface thermodynamics. Mr. LI.

6411. ***PHYSICAL METALLURGY I.*** Credit 3 hrs. Fall. 3 Lect. Not offered after 1963-1964. See 6435. Prereq., 6301 and 6302 (or 6353, 54). Discussion of the structural basis of behavior of materials with emphasis on metallic materials. Topics include dislocations, two-dimensional structural discontinuties, plastic deformation, nucleation, solidification, corrosion, diffusion, oxidation, radiation damage,

theory of alloys, electrical and magnetic properties, recovery, recrystallization and grain growth, solid state transformations (diffusionless and diffusion-controlled), hardenability. Mr. WEART.

6314. *MATERIALS SCIENCE II (a).* Credit 3 hrs. 2 Lect. 1 Lab. Prereq., 6311. The objectives and philosophy of Materials Science I are continued to include chemical behavior, properties of surfaces, properties of composite materials, specific applications of engineering materials, dielectric behavior, charge and heat transport in solids, semiconductor properties and the behavior of magnetic materials.

6412. *PHYSICAL METALLURGY II.* Credit 3 hrs. Spring. 3 Lect. See 6435. Prereq., 6411. This course is a continuation of 6411. Mr. WEART. Not offered after 1964–1965.

[**6423. *THERMODYNAMICS.*** Credit 3 hrs. 3 Lect. Prereq., 8121 or equivalent. Application of thermodynamics, topics include solutions, phase equilibria, defects in solids, surfaces and order-disorder reactions. Mr. LI. First offered in fall 1965.]

[**6432. *MECHANICAL METALLURGY.*** Credit 3 hrs. 3 Lect. Prereqs., 6301, 6311 and 6313. This course will replace 6503. Elastic, plastic, and fracture phenomena in metallic solids, including yielding, strain hardening, brittle fracture, creep and fatigue. Mr. SMITH. First offered in spring 1965.]

6435. *PHYSICAL METALLURGY* (Old 6412) Credit 4 hrs. Fall. 3 Lect. 1 Lab. Prereqs., 6302, 6311, Physics 314. 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. Mr. WEART.

6442. *MATERIALS PROCESSING I.* (Chemical) Credit 4 hrs. Spring. 3 Lect. 1 Lab. Recovery and refining of metals. Production of ferrous and non-ferrous alloys. Manufacture and utilization of refractories. Mr. GREGG.

[**6443. *MATERIALS PROCESSING II*** (Mechanical) Credit 4 hrs. Spring. 3 lect. and 1 lab. Prereq., 6435. A course relating basic and applied sciences to the processing of metallic and non-metallic materials, and developing a critical analysis of processing methods. The effect of processing on the properties of the materials, and control of material properties by variations in processing is emphasized. Also considered are the effects of environmental conditions and the kinetics of the processes.

Lecture material emphasizes the theoretical principles involved in processing, while the laboratory, which is integrated with the lectures, includes experiments involving both principles and actual processing procedures. Processing methods considered include solidification, deformation, heat treatment, material bonding, material removal, consolidation of powders and others. Mr. BURTON. First offered in 1965.]

6503. *SERVICE BEHAVIOR OF METALS.* Credit 3 hrs. Fall. 3 lect. Prereq., 6412. 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. Mr. SMITH.

6504. *UNIT PROCESSES IN METALLURGY.* Credit 3 hrs. Fall. 1 Lect. 1 Lab. with reports. Experimental study of important processes in metallurgy, including generation of furnace atmospheres, furnace design and performance, determination of rates of heating and cooling, and electrochemical operations. Reports based on the experimental data, discussing principles involved in the operations, are important. Mr. GREGG.

6506. *METALLURGICAL DESIGN.* Credit 3 hrs. Spring. Prereq., 6503. A seminar course using a modified case-history approach to problems and current developments in metallurgical engineering. Mr. SMITH.

[**6524. *KINETICS OF REACTIONS IN SOLIDS.*** Credit 3 hrs. 3 Lect. Prereq., 6423 or equivalent. Designed for advanced undergraduates; considers rate theory, transport process, irreversible thermodynamics and their application. Mr. LI. First offered spring 1966.]

6539. *PRINCIPLES OF METALLURGICAL ENGINEERING.* Credit 3 hrs. Fall. 3 Lect. Prereq., 6442 or consent of instructor. Discussion and calculations concerning fuels, fluid flow, heat flow, roasting and sintering, gas cleaning, and application of thermochemical data to metallurgical processes. Mr. GREGG.

6553, 6554. *SENIOR PROJECT.* Credit 2 hrs. Fall-spring. Research on an individual problem in metallurgical engineering. Staff.

6555, 6556. *ADVANCED PROJECT.* Credit as arranged. Fall-spring. Staff.

[**6651. *PHYSICAL METALLURGY OF FERROUS MATERIALS.*** Credit 2 hrs. 2 Lect. Prereq., consent of instructor. Study of the

basic effects of alloying on the structure and properties of steels, and the application of this knowledge to the design of modern high-strength, stainless, or heat-resistant steels and of steels for tools and dies. Mr. Smith. Offered alternate years commencing fall 1964.]

6661. ***METALS AT ELEVATED TEMPERATURES.*** Credit 2 hrs. Fall. 2 Lect. Offered alternate years commencing fall 1963. Prereq., consent of the instructor. Evaluation and application of metals for use at service temperatures. Emphasis is placed on nature of creep flow and fracture at elevated temperatures. Attention is also paid to scaling, metallurgical instability, and pertinent physical properties. Mr. Smith.

[6662. ***REFRACTORY MATERIALS.*** Credit 3 hrs. Spring. 2 Lect. Lab. demonstrations and visits. The lectures will review the crystallography, rheology, and engineering characteristics of refractory metals (tungsten, molybdenum, columbium, and tantalum): graphites; refractory oxides (magnesia, alumina, zirconia, beryllia and thoria); and the refractory compounds, carbides, nitrides, borides and beryllides). Laboratory demonstrations will supplement the lectures, illustrating pyrolitic techniques in preparing graphites and compounds, and the melting, joining, and zone refining by electron beam methods necessary for the refractory materials. Research laboratories actively involved in studying these materials will be visited, and key articles in the current literature will be reviewed to augment the lectures. Mr. Scala. Not offered in 1963-1964.]

6665. ***MATERIALS FOR SPACECRAFT AND MISSILES.*** Credit 2 hrs. Fall. 2 Lect. The basic phenomena and interactions occurring in reentry, space environment, propulsion and conversion for electrical power will be reviewed as they apply to materials behavior and properties. The principal problems involving mechanical, chemical, electrical and/or aerodynamics, interactions will be discussed relative to the compromises in translating the system and mission requirements into working solutions through materials. Supersonic powered flight vehicles, ballistic missiles, and space vehicles will be reviewed as engineering applications of materials. Mr. Scala.

6669. ***INTRODUCTORY PHYSICAL CERAMICS.*** Credit 2 hrs. Spring. 2 Lect. The properties and behavior of ceramics as single and poly-crystalline 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 behaviors during sintering and forming and as thermal, electrical and mechanical properties, with discussions on nucleation, crystal and grain growth and vitrification. Mr. Scala.

6671. ***PRINCIPLES OF POWDER METALLURGY.*** Credit 3 hrs. Fall. 2 Lect. 1 Lab. Offered on demand. Following brief consideration of industrial powder-metallurgy equipment, including dies, presses, and sintering furnaces, and industrial applications such as porous products, permanent magnets, refractory metals, cemented carbides, cermets, etc., the theory of powder metallurgy is treated critically. Emphasis is on the theories of compacting and sintering, diffusional processes, and surface chemistry. The theories, applications, and limitations of hot pressing are examined critically. Laboratory experimentation is primarily concerned with fundamental investigation of compacting, bonding, sintering, hot pressing, infiltration of porous networks, etc. Laboratory studies of surface chemistry and surface activities are included. Mr. Burton.

6681. ***ADVANCED EXPERIMENTAL METALLURGY.*** Credit 3 hrs. Fall. 2 Labs. Experiments using advanced metallurgical laboratory techniques, with discussions of the principles involved and the results of the experiments. Experiments are available in the fields of physical, chemical and mechanical metallurgy; metallography; materials processing; and materials properties. The student is expected to perform approximately six experiments, selected to meet his individual needs. Independent work by the student is stressed, with emphasis both on the experimental method and the metallurgical phenomena. Mr. Burton and staff.

6710. ***TRANSPORT PROCESSES.*** Credit 3 hrs. Spring. 3 Lect. Prereqs., 6524, Physics 314, or equivalents. Discussion of transport of mass and energy in solid systems with emphasis on mass transport. Phenomenological diffusion theories; the diffusion equation, equilibrium and non-equilibrium thermodynamic theories. Description of atomic diffusion: self-diffusion, effects of composition, pressure. Diffusion of imperfections. Simultaneous mass and energy transport, ionic solids, semiconductors, thermal and electrodiffusion. Mr. Weart.

6732. ***ADVANCED METALLOGRAPHY.*** Credit 3 hrs. Spring. Prereqs., 6301 and 6302 or equivalent. Reciprocal lattice, oscillating and rotating crystal X-ray diffraction methods. Diffuse X-ray scattering effects, Quantitative optical metallography, stress measurement by X-ray diffraction. Theory of electron microprobe, thermionic and field emission microscopy, microradiography. X-ray diffraction microscopy. Application of metallographic

methods will be illustrated using metal and ceramic systems undergoing allotropic phase transformations, precipitation, and order-disorder reactions. Lecture problems and laboratory practice will be included. Mr. NEWKIRK.

6872. ***NUCLEAR MATERIALS TECHNOLOGY.*** Credit 2 hrs. Spring. 2 Lect. Prereq., consent of instructor. Production of fissile, source materials, and other materials used in nuclear reactors. Behavior of materials in nuclear reactors, including deterioration by corrosion and irradiation. Problems involved in connection with fuel elements. Fabrication of reactor components. Mr. GREGG.

6911. ***SEMINAR IN NON-CRYSTALLINE MATERIALS.*** Credit 3 hrs. Fall. 3 Lect. Prereqs., 6435, 6524 or equivalents. Discussion of those condensed phases characterized by the absence of long-range order, viz., liquids and glasses. The nature of the liquid and glassy states of atomic, molecular, and polymeric materials is examined via their structure and properties; theories of the liquid state are reviewed to provide a background for a discussion of crystallization vs. glass formation. Mr. WEART.

6961–6962. ***GRADUATE SEMINAR.*** Credit 1 hr. Fall and Spring. Objectives are (1) to provide a forum in which subjects at the forefront of metallurgical science and engineering can be effectively discussed, (2) to develop the student's ability to communicate technical ideas effectively through oral presentations, and (3) to give the student practical experience in organizing and conducting efficient technical meetings. Mr. BURTON.

6980. ***RESEARCH IN METALLURGICAL ENGINEERING.*** Fall-spring. Credit as arranged. Thesis research under guidance of a member of the staff. Staff.

AEROSPACE ENGINEERING

7101. ***FUNDAMENTALS OF AERODYNAMICS.*** Credit 3 hrs. Fall. Prereq., engineering mechanics. Properties of gases and fluids. Kinematics of fluid flows. Equations of motion for an incompressible fluid and Bernoulli's equation. Flow around simple bodies, thin airfoils and wings. Basic properties of compressible flow: the energy relations, channel flows. Prandtl-Meyer and shock waves. Small perturbations at subsonic, transonic, supersonic, and hypersonic speeds. Introduction to viscous-flow theory, boundary-layer equations and the integral method. Transition between laminar and turbulent flows. Mr. SHEN.

7102. ***FUNDAMENTALS OF ASTRONAUTICS.*** Credit 3 hrs. Spring. Prereq., engineering mechanics and thermodynamics. Performance of chemical- and nuclear-rocket systems, performance in central force fields, optimization of powered trajectories, perturbations of trajectories. Solid- and liquid-propellant rockets, ion and plasma propulsion, photon propulsion, and solar sailing, relativistic rocket mechanics. Mr. TURCOTTE.

7203. ***GASDYNAMICS I.*** Credit 3 hrs. Prereq., engineering thermodynamics. Thermodynamics of gases and gas mixtures; kinetic theory, transport properties; introduction to statistical mechanics, chemical equilibria, and reaction rates; derivation of fundamental equations of gasdynamics; acoustics. Mr. TURCOTTE.

7204. ***GASDYNAMICS II.*** Credit 3 hrs. Prereq., 7203 or 8121. One-dimensional gasdynamics, weak and strong shock limits, shock-tube theory, method of characteristics, blast waves, effects of viscosity and thermal conductivity, one-dimensional gasdynamics of a dissociating gas, one-dimensional gasdynamics of an ionized gas. Mr. TURCOTTE.

7206. ***INTRODUCTION TO MAGNETOHYDRODYNAMICS.*** Credit 3 hrs. Spring. Prereq., 7203. Review of electrodynamics, conduction of electricity in gases, equations of motion of magnetohydrodynamics, solutions for special cases and under various approximations, magnetohydrodynamic waves, phenomena in rarefied gases. Mr. RESLER.

7207. ***DYNAMICS OF RAREFIED GASES.*** Spring. Credit 3 hrs. Review of classical kinetic theory of gases. The Boltzmann equation, the Chapmann-Enskog and Grad solutions for slightly nonuniform flows. The hydrodynamic equation. Studies of flow problems involving gases in the regime where the mean free path becomes comparable to pertinent body dimensions; transition between continuum and free-molecule flow regimes. Mr. SHEN.

7208. ***HYPERSONIC-FLOW THEORY.*** Credit 2 hrs. On demand. Prereqs., 7301, 7303. General features of hypersonic flow; the role played by the ratio of specific heats; normal, oblique and curved shock relations; vorticity and shock curvature; irrotational small-disturbance similitude, the principle of equivalence; blast-wave analogy; Newtonian theory with shock-layer structures; optimum bodies; boundary-layer hypersonic-flow interactions; real-gas effects. Mr. SEEBASS.

7301. ***THEORETICAL AERODYNAMICS I.*** Credit 3 hrs. Fall. Prereq., differential equations, intermediate mechanics or introduction to theoretical physics. Introduction to theoretical hydrodynamics. Ideal fluids. The boundary-value problems of steady and non-steady two- and three-dimensional potential flows with special attention to flows produced by the motion of solid bodies. Vector methods and complex variable are used extensively. Mr. SEARS.

7302. ***THEORETICAL AERODYNAMICS II.*** Credit 3 hrs. On demand. Prereqs., 7301, 7303. Wing theory; thin-airfoil theory, two-dimensional airfoil theory. Prandtl wing theory, lifting surfaces, general multiple theory, nonstationary wing theory. Correction for compressibility (linearized theory). Wing theory for supersonic speeds; source and sink methods and extensions, conical-flow methods, nonstationary cases.

7303. ***THEORETICAL AERODYNAMICS III.*** Credit 3 hrs. Spring. Prereqs., 7204, 7301. The aerodynamics of compressible fluids; equations of motion, small-perturbation theory (subsonic and supersonic); Janzen-Reyleigh theory, the hodograph methods, the limiting line, the method of characteristics, Prandtl-Meyer flow, hypersonic flow. Mr. SEEBASS.

7304. ***THEORETICAL AERODYNAMICS IV.*** Credit 3 hrs. Fall. Prereq., registration in 7301. The aero-dynamics of viscous fluids; the boundary layer, heat transfer, fundamentals of boundary-layer stability. Turbulence, the fundamentals of isotropic turbulence. Mr. SHEN.

7801. ***RESEARCH IN AEROSPACE ENGINEERING.*** (Credit to be arranged.) Prereq., 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. Prereq., admission to the Graduate School of Aerospace Engineering. Lectures by staff members, graduate students, personnel of Cornell Aeronautical Laboratory, 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. Prereq., approval of the Director.

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. Through the year. 3 Rec. Primarily for candidates for the degree of Bachelor of Engineering Physics. Introduction to classical thermodynamics, kinetic theory of gases, and statistical mechanics. Application to physical and engineering problems. Mr. RESLER.

8131. ***MECHANICS OF CONTINUA.*** Credit 3 hrs. Spring. 3 Lect. Prereqs., Math. 616, 622 or permission of the instructor. Stress and strain tensors; fundamental equations of motion in continuous media; generalized equation of state; applications to special topics of general and engineering interest in elasticity, wave propagation, vibration, incompressible and compressible fluids, viscous flow, etc. Mr. SEARS.

8252. ***SELECTED TOPICS IN PHYSICS OF ENGINEERING MATERIALS.*** Credit 3 hrs. Fall term. Primarily for fifth year students in engineering physics; others with consent of instructor. Seminar-type discussion of a number 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. Staff.

8255. ***CRYSTAL DISLOCATION THEORY.*** Credit 3 hrs. Spring. 3 Lect. Prereqs., consent of the instructor, equivalents of Math 616 or 1182, and Physics 454. Primarily for graduate students in solid state physics. The theoretical basis for elementary concepts of dislocations, elastic continuum models including continuum field theory, crystallogra-

phy of line and plane defects, and the dislocation core problem are emphasized. The origin of dislocations and some of their properties such as electron scattering, perturbations of electronic structure, interactions with point defects are discussed. Crystal growth, creep, and plasticity and fracture are considered as applications of dislocation theory. Mr. WEBB or Mr. RUOFF.

8256. ***THEORETICAL MATERIALS—CRYSTAL MECHANICS.*** Credit 3 hrs. Fall. Prereq., 1243 or equivalent. Primarily for graduate students. Mechanical and physical characteristics of crystals from a classical viewpoint, including crystallography, symmetry elements, mechanical and physical properties of crystals of differing symmetry, influence of crystal structure upon elastic constants, theories of elastic constants for metals and ionic crystals; crystallography of simple glide and twinning for different crystal structures, double slip, cross slip, deformation bands. Mr. JOHNSON.

8262. ***PHYSICS OF SOLID SURFACES.*** Credit 3 hrs. Spring. (Given in odd numbered years.) A lecture course for graduate students and upperclassmen. Permission of instructor required. An introductory review of advances in theories of surface phenomena normally not covered in conventional courses in solid state physics or physical chemistry. Phenomena considered include thermodynamics of surfaces, atomic and molecular processes, electron emission effects, interfacial effects in solids and phase transformations at surfaces. Mr. RHODIN.

8265. ***THEORY OF REACTION RATES IN SOLIDS.*** Credit 3 hrs. Spring. 3 Lect. (Given in even numbered years.) Prereq., permission of instructor. Directed toward graduate students and advanced engineering undergraduates concerned with the application of physical-mathematical concepts to the interpretation of rate processes in metals. The theory of absolute rate processes is presented in detail with reference to the kinetics and thermodynamics of physical and chemical changes primarily in metals. Rates of physical and chemical processes are considered from first principles, utilizing such fundamental properties as atomic configurations, dimensions, and interatomic forces of the reacting molecules. The analytical description is introduced in terms of statistical mechanics, the Arrhenius equation, potential energy surfaces, properties of the activated complex, and the behavior of transition states. Quantitative applications are developed in terms of atomic mechanisms with reference to transport and transformation processes in metals such as diffusion, nucleation and growth, creep, precipitation, and other physical and chemical solid-state processes. Mr. RHODIN.

8301. ***INTRODUCTION TO ATOMIC AND NUCLEAR PHYSICS.*** Credit 3 hrs. Fall. 3 Lect. Prereqs., two years of college physics and calculus through differential equations. Concepts of atomic structure of matter; fundamentals of quantum theory, and applications to structure of atoms, molecules and nuclei. At the level of *Fundamentals of Modern Physics* by Eisberg. Mr. FISHER. (This course will be replaced by Physics 314 beginning in the fall of 1964.)

8302. ***NUCLEAR AND REACTOR PHYSICS.*** **(Old 8311)** Credit 3 hrs. Spring. 3 Lect. Prereq., 8301 or Physics 314 or Physics 443. Nuclear particles, nuclear structure, properties of nuclei; radioactivity, applications of radioactivity; nuclear reactions; neutron reactions, nuclear fission. Neutron slowing down and diffusion; elementary reactor theory, types of reactors, reactor design criteria. At the level of *Nuclear Physics* by Kaplan and *Nuclear Reactor Engineering* by Glasstone. Mr. FISHER.

8309. ***LOW ENERGY NUCLEAR PHYSICS.*** Credit 3 hrs. Fall. 3 Lect. Prereqs., a one-year introductory course in atomic and nuclear physics including quantum mechanics, such as 8301–8302 or preferably Physics 443–444; Math 215–216 or equivalent. Primarily for graduate students in the field of nuclear science and engineering. Low energy nuclear physics as an organized body of exeprimental facts. Properties of ground and excited states of nuclei; models of nuclear structure; low energy nuclear reactions—scattering, absorption, fission, resonance effects, coherent scattering effects. At a level between *Introductory Nuclear Physics* by Halliday and *Nuclear Physics* by Fermi. Mr. CLARK.

8312. ***REACTOR THEORY I.*** Credit 3 hrs. Spring. 3 Lect. Prereqs., 8309 and co-registration in Math 416. The theory of neutron diffusion and slowing down is developed, and applied to basic integral experiments and to criticality calculations. Neutron transport theory is introduced and applied to some problems for heterogeneous reactors. At the level of *Reactor Analysis* by Meghreblian and Holmes. Mr. NELKIN.

[8313. ***REACTOR THEORY II.*** Credit 3 hrs. Fall. 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. Usually given each year, but not offered in 1963.]

[8314. ***NEUTRON TRANSPORT THEORY.*** Credit 3 hrs. Spring. 3 Lect. Prereq., 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. Not given in 1963–1964.]

8333. ***NUCLEAR REACTOR ENGINEERING.*** Credit 3 hrs. Fall. 3 Lect. Prereq., 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. Mr. CADY and staff.

8334. ***NUCLEAR ENGINEERING SEMINAR.*** Credit 3 hrs. Spring. Prereq., 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. Messrs. HOWE, CADY.

8342. ***READING COURSE IN RADIOCHEMISTRY.*** Credit 2 hrs. Spring. Primarily for graduate students. Reading assignments in the general field of radio-chemistry. Meetings for discussions at the convenience of the group, possibly for two hours every other week. Slanted toward the interests of the students, the course may include such topics as nuclear fission, radio-chemistry, nuclear concepts in geochemistry, neutron activation analysis, beta decay studies, radiation chemistry, hot-atom chemistry, biological effects of radiation, cosmic chemistry, nuclear reactions, neutrino searches, elemental abundances, tracer techniques, and applications in various fields. Mr. FISHER.

8351. ***NUCLEAR MEASUREMENTS LABORATORY.*** Credit 3 hrs. Either term. Two 2½ hour afternoon periods. Prereqs., 8302 or 8309, or 8311 or Physics 444. Laboratory experiments plus lectures on interaction of radiation with matter and on radiation detection, including electronic circuits. Some twenty different experiments are available in the fields of nuclear and reactor physics. Among these are experiments on emission and absorption of radiation; on radiation detectors and nuclear electronic circuits; on interactions of neutrons with matter (absorption, scattering, moderation, and diffusion); on activation analysis and radiochemistry; and on properties of a subcritical assembly. Many of the experiments use the TRIGA Reactor. The student is expected to perform eight to ten experiments, selected to meet his needs. Some stress is laid on independent work by the student. Mr. CLARK and staff. (After 1963–1964 this course will be offered in spring only.)

8352. ***REACTOR PHYSICS LABORATORY.*** Credit 3 hrs. Spring. Two 2½ hour afternoon periods. Prereqs., 8351 and 8312. Laboratory experiments plus lectures on methods of reactor physics measurements. Experiments utilizing the Zero Power Reactor critical facility as well as the TRIGA Reactor are included. Mr. CLARK and staff. (After 1963–1964, this course will be offered in fall only.)

8512. ***ELECTRON MICROSCOPY.*** Credit 3 hrs. Spring. Prereq., permission of the instructor. Lect. Lab. Hours to be arranged. Basic electron optics, image formation and interpretation, construction and operation of the electron microscope, applications in physics, chemistry, and biology.

8517. ***ELECTRON OPTICS AND ITS APPLICATIONS.*** Credit 3 hrs. Fall. Prereq., Physics 225 (Physics 215 advised but not required). Electron beam formation, Gaussian dioptrics and aberrations of electron lenses, application including cathode ray tube, electron microscope, beta ray spectrometer, mass spectrometer.

INDUSTRIAL ENGINEERING

Since several of the courses listed here were formally given under the 3200 series of numbers when the industrial engineering activity was a part of the School of Mechanical Engineering, the old number is given in parentheses if the course is similar to one formerly offered.

SERVICE COURSES

[9101. ***INDUSTRIAL ORGANIZATION AND MANAGEMENT.*** **(Old 3235)** 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 1963–1964.]

[9110. ***INTRODUCTION TO INDUSTRIAL ENGINEERING.*** Credit 4 hrs. Spring. 3 Rec. 1 Lab.-Comp. Prereqs., 9153 and 9170. An introduction to modern industrial engineering with emphasis on the design activities of industrial engineers in specifying workplace methods, the integration of many 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 mechanical, electrical, and civil engineers. First offered in 1965–1966.]

9120. ***SYSTEMS ENGINEERING.*** **(Old 3261)** Credit 3 hrs. Spring. 2 Rec. 1 Lab. Elective for graduate students and qualified undergraduates not majoring in industrial engineering. Prereq., 9170. 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.

9153. ***ENGINEERING ECONOMIC ANALYSIS.*** **(Old 3253)** 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. ***INDUSTRIAL AND ENGINEERING STATISTICS.*** **(Old 3241)** Credit 3 hrs. Either term. 2 Rec. 1 Comp. Prereq., Math. 192. 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.

9180. ***DIGITAL COMPUTER PROGRAMMING.*** Credit 1, 2, or 3 hrs. Fall. 2 Rec. 1 Comp. Intended for graduate students; undergraduates should ordinarily take 9381. Prereq., consent of instructor. Intended to prepare student to use the medium and large scale digital computers of the Cornell Computing Center in a language other than CORC. The course consists of three independent five week sections with one hour of credit for each section. Each section will consider one language from the following: FORTRAN, ALGOL, COBOL, CAP, CODAP. The particular languages to be covered and the order of presentation will be posted at the Computing Center at the beginning of the term. Machine operation, program test procedures and input-output operations including the use of magnetic tape systems will also be covered. Mr. RUDAN or Mr. SALTZMAN.

9182. ***DATA PROCESSING SYSTEMS.*** Credit 3 hrs. Fall. 2 Rec. 1 Comp. Elective for graduate students and upperclass undergraduates. Prereq., a course in industrial accounting (concurrent registration is acceptable). An introductory course in modern business data systems. Includes introduction to appropriate data handling equipment and techniques of systems analysis and design. Problem definition and description is by COBOL and DETAB languages; laboratory work is in COBOL (Control Data 1604) and SPS (IBM 1401). Control and decision functions as well as routine accounting operations; emphasis is more on problem analysis and systems planning than on programming. Mr. CONWAY or Mr. SALTZMAN.

REQUIRED COURSES

[9310. ***INDUSTRIAL ENGINEERING ANALYSIS AND DESIGN I.*** Credit 4 hrs. Fall. 2 Lect. 2 Comp. Prereqs., 9370, 9381. Introduction to engineering analysis and design. Background and environmental factors. Concentration on design problems of the single workplace, and on methods of measurement and evaluation. Specific topics include elements of the design process, problem definition, restraints, synthesis, analysis, etc.; graphical activity models and other forms of modeling; man-machine and small-group activity analysis; human factors and design of manual operations; general problem of measurement and basic methods for work measurement; rating, allowances, and associated problems; measurement by work sampling; standard time data; other methods in labor measurement; application of queuing theory to design problems; job evaluation techniques and related methods for measurement and evaluation; etc. First offered in 1964–1965.]

[9311. ***INDUSTRIAL ENGINEERING ANALYSIS AND DESIGN II.*** Credit 4 hrs. Fall. 2 Lect. 2 Comp. Prereqs., 9320, 9351. The design of complex systems such as production plants,

warehousing and distribution systems, other systems in which discrete flow occurs; information systems with feedback. Applications of simulation in the design and analysis of such systems. First offered in 1965–1966.]

[**9320.** ***ANALYTICAL METHODS IN INDUSTRIAL ENGINEERING.*** Credit 4 hrs. Spring. 1 Lect. 2 Rec. 1 Comp. Prereqs., 9310 and 9351. 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 the inventory problem. First offered in 1964–1965.]

9350. ***PRINCIPLES OF COSTING AND CONTROL.*** Credit 3 hrs. Spring. 2 Rec. 1 Comp. An introduction to problems of cost determination and allocation. Differences between accounting and engineering objectives in cost finding and cost procedures. Cost concepts and characteristics, and the inexactitude of cost figures relative to engineering problems and decisions. Costing techniques and procedures.

[**9351.** ***COST ANALYSIS AND CONTROL.*** Credit 3 hrs. Fall. 2 Rec. 1 Comp. Prereq., 9350. A continuation of the preceding course with emphasis on the analysis, interpretation, and uses of such data in establishing control over operations being judged against cost criteria. Also, the uses of such data for evaluation and prediction of future design and/or operations. The choice of proper cost data for use in economic models of interest to engineers, i.e., replacement and renewal models, linear programming models, make-buy models, etc. First offered in 1964–1965.]

[**9352.** ***INDUSTRIAL AND ENGINEERING ADMINISTRATION.*** Credit 3 hrs. Spring. 3 Lect. Prereq., fifth year or graduate standing. Study of related topics in engineering administration, organization, and economic analysis. Applications of selected theoretical concepts to practical problems of modern commercial, governmental, or military activity. Development of selected specialized operational planning and control techniques. First offered in 1964–1965.]

9360. ***INTRODUCTION TO PROBABILITY THEORY WITH ENGINEERING APPLICATIONS.*** Credit 3 hrs. Fall. 3 Lec.-Rec. Prereq., Math. 192. 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 Lect.-Rec. 1 Comp. Prereq., 9360. The applications 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 MODERN DIGITAL COMPUTATION.*** Credit 3 hrs. Either term. 2 Rec. 1 Comp. Required of I.E. majors and elective for upper class undergraduates and graduate students. (See 9582.) Survey of the field of the computer sciences. Development of the modern digital computer, principles and characteristics of current equipment, machine and higher-level information processing languages. Laboratory work involves use of equipment of the Cornell Computing Center, but this is not essentially a course in programming (see 9180). Emphasis is placed on the digital computer as a general-purpose device for storing, retrieving, processing, and transmitting information in addition to its role as an arithmetic calculator. Breadth of present and potential application is stressed by considering areas such as artificial intelligence, integrated decision and control systems, Monte Carlo analyses, simulated experimentation, information retrieval, and manufacturing automation. Messrs. Conway, Maxwell, Ruban, or Saltzman.

9398, 9399. ***PROJECT.*** Max. credit 6 hrs. Both terms. Prereqs., 9320 and concurrent registration in 9311. Project work requires the identification and analysis of both professional and research problems in industrial engineering. The projects emphasize analytic ability and the synthesis of feasible solutions. Projects can be done individually or in groups of up to eight. The problem definition and the subsequent analysis and synthesis are the concern of the student. Faculty guidance and participation are available at any time for all projects. In addition, progress must be reviewed on a regular schedule with the faculty adviser.

ELECTIVE AND GRADUATE COURSES

[**9501.** ***ENGINEERING ADMINISTRATION.*** Credit 3 hrs. Fall. 2 Lect. Organization of engineering function; planning and analysis of engineering activities; provision of engineering support through specialized services of technical information; laboratory facilities, editorial, communication, etc.; personnel problems of recruiting, professional development and evaluation; discussion of sociological and psychological studies of scientific and engineering personnel; funding, budgeting, and related financial problems. Not offered in 1963–1964.]

[**9502.** ***PERSONNEL MANAGEMENT*** **(Old 3232)** Credit 3 hrs. Fall. 3 Rec. Intended for graduate students but open to qualified undergraduates. Prereq., 9170 or equivalent. Techniques of employee selection and evaluation, job evaluation, training, motivation; personnel department organization and interdepartmental relations. Not offered in 1963–1964.]

9510. ***WORK DESIGN AND MEASUREMENT.*** **(Old 3266)** Credit 3 hrs. Spring. 2 Rec. 1 Lab. Intended for graduate students but open to qualified undergraduates. Prereq., 9310, 3262, 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 microsystems design problem, including emphasis on the behavioral aspects and wage incentives.

9511. ***MANUFACTURING ENGINEERING.*** **(Old 3267)** Credit 3 hrs. Spring. 2 Rec. 1 Comp. Intended for graduates or qualified undergraduates. Prereq., 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. Problems of modelling a proposed design to serve various functions will be discussed including laboratory tests of designs through simulation.

[**9512.** ***STATISTICAL METHODS IN QUALITY AND RELIABILITY CONTROL.*** Credit 3 hrs. Spring. 3 Lec. Prereq., 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. Not offered in 1963–1964.]

9520. ***MATHEMATICAL PROGRAMMING.*** Credit 3 hrs. Spring. 2 Rec. 1 Comp. Prereq., 9360 or equivalent. 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.

9521. ***PRODUCTION PLANNING.*** Credit 3 hrs. Spring. 2 Rec. 1 Comp. Intended for graduate students but open to qualified undergraduates. Prereq., 9170 or permission. Scheduling of manufacturing operations—forecasting, leveling, explosion, loading, sequencing. The planning and control of inventories. Emphasis on mathematical and statistical methods of performing these functions, including development of decision rules and reactive control systems.

9522. ***OPERATIONS RESEARCH I.*** Credit 3 hrs. Spring. 2 Rec. 1 Comp. Prereqs., 9160, 9381, or permission. Model design, methodology of operations research, linear programming, transporation 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. Fall. 2 Rec. 1 Comp. Prereqs., 9522, or 9320, 9370. 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. First offered in 1964–1965.]

9524. ***PROBLEMS IN OPERATIONS RESEARCH.*** Credit 3 hrs. 1 2-hr. meeting a week. Prereq., 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. 2 Rec. 1 Comp. 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. Mr. CONWAY or Mr. MAXWELL.

9560. *APPLIED STOCHASTIC PROCESSES.* Credit 3 hrs. Spring. 2 Rec. 1 Comp. Intended for graduate students but open to qualified undergraduates. Prereqs., 9360 and 9370 or permission. An introduction to the theory of stochastic processes, with emphasis on applications to science and engineering. Topics drawn from sequences of random variables; Markov chains; renewal theory; applications to waiting time problems, to counter problems, and to reliability theory; birth and death processes; multiplicative processes; Gaussian processes; stationary processes; correlation and spectral distribution; applications to communication theory.

9561. *QUEUING THEORY.* Credit 3 hrs. Fall. 2 Rec. 1 Comp. Intended primarily for graduate students. Prereqs., 9360 and permission of the instructor. Definition of a queuing process. Explicit solutions of queuing problems when the arrival and service distributions are exponential or Erlang. A detailed study of the one-server problem for general distributions: the basic Wiener-Hopf equation; existence and uniqueness of stable solutions; approaches to solving the basic equation. Multiserver problems; bulk service; queues in series. Applications to specific engineering problems such as shop scheduling, equipment maintenance, and inventory control.

9562. *INVENTORY THEORY.* Credit 3 hrs. 3 Lec. Rec. Intended primarily for graduate students but open to qualified undergraduates. Prereqs., 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.

9570. *INTERMEDIATE INDUSTRIAL AND ENGINEERING STATISTICS.* **(Old 3243).** Credit 3 hrs. Spring. 2 Rec. 1 Comp. Intended for graduate students but open to qualified undergraduates. Prereq., 9370 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.* **(Old 3244).** Credit 3 hrs. Fall. 2 Rec. 1 Comp. Intended for graduate students. Prereq., 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. (Offered in alternate years. Given in 1963–1964.)

[**9572. *STATISTICAL DECISION THEORY.*** Credit 3 hrs. Fall. 2 Rec. 1 Comp. Intended for graduate students. Prereqs., 9360 and 9570, or equivalent. The general problem of statistical decision theory and its applications. The comparison of decision rules; Bayes, admissible, and minimax decision rules. Problems involving a sequence of decisions over time, including sequential analysis. Use of the sample cumulative distribution function, and other nonparametric methods. Applications to problems in the areas of inventory control, sampling inspection, capital investment, and procurement. Not offered in 1963–1964.]

[**9573. *STATISTICAL MULTIPLE DECISION PROCEDURES.*** Credit 3 hrs. Fall. 2 Rec. 1 Comp. Intended for graduate students. Prereq., 9570 or permission of the instructor. The study of multiple-decision problems where choices must be made between two or more courses of action. The Wald two decision problem; the relationship of classical sequential analysis to multiple decision procedures; single-sample procedures; sequential analogs of single sample procedures; development of sequential multiple decision procedures. Applications in ranking problems where preference according to various criteria is desired, i.e., ranking vendors by quality, of missiles by range or precision, of system components by reliability, etc. Offered in alternate years. Given in 1964–1965.]

9579. *SELECTED TOPICS IN INDUSTRIAL STATISTICS.* **(Old 3245).** Credit 3 hrs. Either term. 2 Rec. 1 Comp. Intended for graduate students. Prereq., 9570 or permission. Selected topics chosen from such fields as non-parametric statistical methods, sequential analysis, multivariate analysis.

9580. *DIGITAL SYSTEMS SIMULATION.* Credit 3 hrs. Fall. 2 Rec. 1 Comp. Intended

for graduate students and qualified undergraduates. Prereqs., 9381 and permission. 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 SIMSCRIPT language. 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.

9581. ***INTEGRATED INFORMATION PROCESSING SYSTEMS.*** Credit 3 hrs. Spring. 2 Rec. 1 Comp. Intended for graduate students but open to qualified undergraduates. Prereq., 9381 or 9182. Concerned with the integration of systems for acquiring, recording, coding, transmitting, filing, storing, retrieving, processing, and reporting information. Theoretical basis in such topics as information theory, data communications, information retrieval, queuing theory, character recognition, and adaptive control theory. Also, implementation problems in equipment capability and compatibility, processing languages, and overall information systems design. Applications in manufacturing—both in accounting and control of operations—merchandising, warehousing, banking, transportation, and military operations.

9582. ***MODERN DIGITAL COMPUTATION.*** Credit 4 hrs. Either term. 3 Rec. 1 Comp. Intended for graduate students but open to qualified undergraduates; consent of instructor required. Covers the same topics as 9381 but with somewhat greater depth and rigor. Meets concurrently with 9381 for 2 recitations each week. Messrs. CONWAY, MAXWELL, RUDAN, or SALTZMAN.

9584. ***STRUCTURE OF COMPUTING LANGUAGES.*** Credit 3 hrs. Spring. 2 Rec. 1 Comp. Intended for graduate students but open to qualified undergraduates. Prereq., 9582 or consent of instructor. Will consider the structure and form of different types of programming languages including assemblers, interpreters, compilers, list processors and tabular languages. Basic techniques for scanning, ordering and translating will be covered. Will consider also advanced programming systems for executive control and multi-processing. Students will design and implement several simple programming languages during the term.

9585. ***COMPLEX INFORMATION PROCESSES.*** Credit 3 hrs. Spring term. 2 Rec. 1 Comp. Elective for graduate students. Prereq., 9582 or consent of instructor. Considers basic theory of automata and complex computer applications in which some degree of artificial intelligence is exhibited. Considers programs which are heuristic, adaptive, or which learn from computation experience. Illustrative applications in game-playing and theorem proving; practical applications in industrial scheduling, line balancing and machine layout. Laboratory work will involve IPL-V programming on the Control Data 1604 of the Cornell Computing Center. Messrs. CONWAY, MAXWELL or SALTZMAN.

9590. ***SPECIAL INVESTIGATIONS IN INDUSTRIAL ENGINEERING.*** 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 administration.

9591. ***INDUSTRIAL ENGINEERING AND ADMINISTRATION 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.

AGRICULTURAL ENGINEERING

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

2. ***INTRODUCTION TO AGRICULTURAL ENGINEERING.*** Credit 2 hrs. Spring. 2 Lect. Limited to students in the five-year agricultural engineering curriculum. The purpose is to introduce the application of engineering principles to problems in agriculture, with a brief history of the development of agricultural engineering in the United States. Problems that are of primary interest to the agricultural engineer are used to provide understanding of the application of principles and to test the students' comprehension of the subject matter. Selected staff.

105. ***ENGINEERING DRAWING.*** Credit 4 hrs. Fall. 2 Lect. 2 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, 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. Department equipment will be utilized to reproduce selected drawing exercises to illustrate the techniques involved and verify line work quality. The first half-hour of the laboratory will be utilized as an instruction-recitation period. Laboratories will be conducted to promote learning through informal student-teacher contact. Mr. LONGHOUSE.

202. ***AGRICULTURAL POWER.*** Credit 3 hrs. Fall. Lect. Lab. Comp. Prereq., Engineering 3601 or the equivalent. Thermodynamic principles applied to internal combustion engines. Application of kinematics and dynamics to tractor design and field use. Elements involved in proper construction, selection, and operation of farm tractors. Emphasis on writing of engineering reports. Mr. SIEMENS.

203. ***AGRICULTURAL MACHINERY.*** Credit 3 hrs. Spring. 2 Lect. 1 Lab. Prereq., Engineering 3341 or the equivalent. The principles of design and development of agricultural machines to meet functional requirements. Emphasis is given to stress analysis, selection of materials of construction, and testing procedures involved in machine and development. Mr. GUNKEL.

220. ***SURVEYING.*** Credit 2 hrs. Spring. 1 Lect. 1 Lab. A study of the principles and practices of surveying measurements. Fundamentals of measurement, sources of errors. Use of steel tape, engineer's level, transit and plane table. Emphasis upon agricultural engineering applications. Mr. LEVINE.

221. ***SOIL AND WATER ENGINEERING.*** Credit 3 hrs. Spring. 2 Lect. 1 Lab. Prereqs., Engineering 2132, 2302, and Agronomy 1, 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. Mr. BLACK.

231. ***AGRICULTURAL STRUCTURES.*** Credit 3 hrs. Spring. 1 Lect. 2 Lab. Prereqs., Engineering 2732 and 3605 or their equivalents. An advanced course in the application of structural design principles to farm buildings. Includes functional requirements, characteristics of materials, structural design, and the principles of environmental control in farm buildings. Mr. SCOTT.

241. ***LOW-COST ROADS.*** Primarily for foreign students. Credit 3 hrs. On demand. Prereq., 2610 or the equivalent. Study of economic importance of routes and selection of roads to be improved; location and design; subgrade soils and stabilization of subgrade soils by use of admixtures, chemicals and bituminous materials; drainage structures; bituminous treatments and bituminous mats for stabilized subgrades. Survey of the experimental work in the use of materials and design and construction of low-cost roads. Mr. SPENCER.

251. ***SPECIAL PROBLEMS IN AGRICULTURAL ENGINEERING.*** Credit 1 or more hrs. Fall or spring. Prereqs., adequate ability and training for the work proposed, and permission to register. (Normally reserved for seniors in upper two-fifths of class.) Special work in any branch of agricultural engineering on problems under investigation by the Department or of special interest to the student, provided, in the latter case, that adequate facilities can be obtained. Staff.

253. ***SPECIAL TOPICS IN AGRICULTURAL ENGINEERING.*** Credit 1 hr. Fall and spring. Open only to seniors. Presentation and discussion of the opportunities, qualifications, and responsibilities for positions of service in the various fields of agricultural engineering. Mr. FRENCH.

260–261. ***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. Staff.

[461. ***AGRICULTURAL MATERIALS HANDLING AND PROCESSES.*** Credit 4 hrs. Fall. 3 Lect. 1 Lab. A study of principles of and equipment for handling agricultural materials, including the development of systems for typical farm operations. Processes such as size reduction, separation, mixing, metering, dehydration, refrigeration, and ventilation as they apply to farm structures and materials are included. Not given in 1963–1964.]

FACULTY AND STAFF

JAMES A. PERKINS, A.B., Ph.D., President of the University.
DALE RAYMOND CORSON, Ph.D., Dean of the College and Professor of Engineering Physics and Physics.
GORDON P. FISHER, D.Eng., Associate Dean of the College and Professor of Civil Engineering.
JOHN F. McMANUS, C.E., Assistant Dean of the College.
DONALD H. MOYER, B.S., M.A., Director of the Office of Student Personnel.
DONALD F. BERTH, B.S.Ch.E., M.S.Ch.E., Administrative Assistant.
JEANETTE WOOD, B.S., Librarian.

AEROSPACE ENGINEERING

WILLIAM R. SEARS, B.Aero.E., Ph.D., Director of the School and John LaPorte Given Professor of Engineering.

PROFESSORS

EDWIN L. RESLER, JR., B.Aero.E., Ph.D., Professor of Aerospace Engineering.
SHAN FU SHEN, B.S., Sc.D., Professor of Aerospace Engineering.

ASSOCIATE PROFESSOR

DONALD LAWSON TURCOTTE, B.S., M.Aero.E., Ph.D., Associate Professor of Aerospace Engineering.

ASSISTANT PROFESSOR

A. RICHARD SEEBASS III, B.S.E., M.S.E., Ph.D., Assistant Professor of Aerospace Engineering.

AGRICULTURAL ENGINEERING

ORVAL C. FRENCH, B.S.A.E., M.S.A.E., Head of Department, Professor of Agricultural Engineering, and Chairman of the Joint Faculty Committee.

JOINT FACULTY COMMITTEE OF AGRICULTURE AND ENGINEERING ADMINISTERING THE AGRICULTURAL ENGINEERING CURRICULUM

NEPHI ALBERT CHRISTENSEN, B.S.C.E., M.S.C.E., Ph.D., Director of the School of Civil Engineering and Professor of Civil Engineering.
WILLIAM HARRY ERICKSON, B.S. in E.E., M.S. in E.E., Assistant Director of the School of Electrical Engineering and Professor of Electrical Engineering.
GEORGE RAYMOND HANSELMAN, M.E., M.S., Assistant Director of the Sibley School of Mechanical Engineering and Professor of Administrative Engineering.
BARBOUR LAWSON HERRINGTON, B.S., Ph.D., Professor of Dairy Chemistry.
GEORGE B. LYON, B.S. in C.E., M.S., Associate Professor of Civil Engineering.
ROBERT MUMFORD SMOCK, B.S., M.S., Ph.D., Professor of Pomology.
STANLEY WHITSON WARREN, B.S., Ph.D., Professor of Farm Management.

PROFESSORS

EDWIN STANLEY SHEPARDSON, B.S., M.S. in Agr., Professor of Agricultural Engineering.
LANDIS LEE BOYD, B.S., M.S., Ph.D., Professor of Agricultural Engineering.
WESLEY WINNFRED GUNKEL, B.S., M.S., Ph.D., Professor of Agricultural Engineering.
JAMES WENDELL SPENCER, B. of C.E., M.C.E., Professor of Agricultural Engineering.

ASSOCIATE PROFESSORS

GILBERT LEVINE, B.S., Ph.D., Associate Professor of Agricultural Engineering.
WILLIAM FREDERICK MILLIER, B.S., Ph.D., Associate Professor of Agricultural Engineering.
RONALD BAY FURRY, B.S., M.S., Associate Professor of Agricultural Engineering.

ASSISTANT PROFESSORS

RICHARD DEAN BLACK, B.S., M.S., Ph.D., Assistant Professor of Agricultural Engineering.
ROBERT THEODORE LORENZEN, B.S.A.E., B.S.C.E., M.S., Assistant Professor of Agricultural Engineering.

CHEMICAL ENGINEERING

CHARLES CALVERT WINDING, B.Ch.E., Ph.D., Director of the School, Herbert Fisk Johnson Professor of Industrial Chemistry, Professor of Chemical Engineering, and Personnel Officer of the School.

EMERITUS PROFESSOR

FRED HOFFMAN RHODES, A.B., Ph.D., Professor of Chemical Engineering, Emeritus.

PROFESSORS

ROBERT KAUL FINN, B.Chem.E., Ph.D., Professor of Chemical Engineering.
J. ELDRED HEDRICK, Ph.D., Professor of Chemical Engineering.
CLYDE WALTER MASON, A.B., Ph.D., Emile M. Chamot Professor of Chemical Microscopy and Professor of Metallography.
JULIAN C. SMITH, B.Chem., Chem.E., Professor of Chemical Engineering.
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