# COLLEGE OF ENGINEERING

1964-65

# THE UNIVERSITY OF MICHIGAN

Official Publication

**VOL. 65, NO. 107, APRIL 3, 1964**

*Entered as second-class matter at the Post Office at Ann Arbor, Michigan. Issued triweekly July through December and semiweekly January through June by The University of Michigan. Office of publication, Ann Arbor, Michigan.*

University of Michigan Official Publication

# College of Engineering

# 1964-1965

# Announcement

Published by the University Ann Arbor

# Office Directory

## GENERAL UNIVERSITY OFFICES

Academic Affairs, Office of, 1524 Administration
Admission of Freshmen, Student Activities Building
Appointments, Bureau of, Student Activities Building
Automobile permits, 3011 Student Activities Building
Business Office, information desk, second floor, Administration
Cashier's Office, 1015 Administration and 2226 Student Activities Building
Director of Admissions, Student Activities Building
D.O.B., 3564 Administration
Eligibility for activities, Student Activities Building
Employment:
  hospital employment, A6002 Hospital
  University offices, 1020 Administration
  men students, Personnel Office, 1020 Administration
Extension Service, 412 Maynard St.
Foreign Student Counselors, International Center
Fraternities, information about, Student Activities Building and Michigan Union
Graduate School, Rackham Building
Health Service, Fletcher Avenue
Housing:
  Married Students, 2364 Bishop St., North Campus
  Men, 3011 Student Activities Building
  Women, 3011 Student Activities Building
Information desk, first floor, Administration
Orientation, 1560 Administration
President's Office, 2522 Administration
Print Lending Library, Student Activities Building
Refund of semester fees, 1513 Administration
Residence Halls:
  Business Manager, 2244 Student Activities Building
  fees, payment of, 2226 Student Activities Building
Scholarship bulletins, Student Activities Building
Secretary of the University, 2552 Administration
Sororities, information about, 1011 Student Activities Building
Student activities, Student Activities Building
Student Affairs, Office of, Student Activities Building
Summer Session Office, 3510 Administration
Veterans Affairs, 2059 Administration Building

## COLLEGE OFFICES

Admissions: Advanced Standing, 259 West Engineering
Deans of the College:
  Dean Stephen S. Attwood, 255 West Engineering
  Associate Dean G. V. Edmonson, 247 West Engineering
  Associate Dean J. C. Mouzon, 248 West Engineering
  Assistant Dean and Secretary, A. R. Hellwarth, 259 West Engineering
  Assistant to the Dean, R. E. Carroll, 268 West Engineering
  Assistant to the Dean, R. H. Hoisington, 259 West Engineering
  Assistant to the Dean, I. K. McAdam, 312 Automotive Engineering Laboratory
  Assistant to the Dean, J. G. Young, 128H West Engineering
Lost and Found:
  Information desk, second floor lobby, Administration
  Office of the Assistant Dean, 259 West Engineering
Placement, student and alumni, 128H West Engineering, J. G. Young, and department offices
Records Office, 263 West Engineering
Transcripts, 263 West Engineering
Transfer students, admission of, 259 West Engineering

# Contents

# Calendar, 1964-65

## SUMMER SESSION, 1964

| | |
|---|---|
| Registration | June 18-19, Thursday-Friday |
| Classes begin | June 22, Monday |
| Independence Day, a holiday | July 4, Saturday |
| Courses end | August 15, Saturday |

## FALL SEMESTER, 1964

| | |
|---|---|
| Orientation | August 24-29, Monday-Saturday |
| *Registration | August 26-28, Wednesday-Friday |
| Classes begin | August 31, Monday |
| Labor Day, a holiday | September 7, Monday |
| Thanksgiving recess begins | November 25, Wednesday (evening) |
| Classes resume | November 30, Monday |
| Study day | December 15, Tuesday |
| Examination period | December 16-22, Wednesday-Tuesday |
| Midyear Graduation | December 19, Saturday |
| Semester ends | December 22, Tuesday |

## SPRING SEMESTER, 1965

| | |
|---|---|
| Orientation | January 11-16, Monday-Saturday |
| *Registration | January 13-15, Wednesday-Friday |
| Classes begin | January 18, Monday |
| Spring recess | March 20, Saturday |
| Classes resume | March 29, Monday |
| Study day | May 7, Friday |
| Examination period | May 10-15, Monday-Saturday |
| Commencement | May 22, Saturday |

## SUMMER, 1965

| | |
|---|---|
| Registration | June 17-18, Thursday-Friday |
| Classes begin | June 21, Monday |
| Independence Day, a holiday | July 5, Monday |
| Eight-week courses end | August 14, Saturday |

This calendar is subject to change.

*For registration schedules, see pages 209 and 210.

# COLLEGE OF ENGINEERING

HARLAN HATCHER, Ph.D., Litt.D., LL.D., *President of the University*
MARVIN L. NIEHUSS, LL.B., *Executive Vice-President of the University*
ROGER W. HEYNS, Ph.D., *Vice-President for Academic Affairs*
STEPHEN S. ATTWOOD, M.S., *Dean of the College of Engineering*
GLENN V. EDMONSON, M.E., *Associate Dean of the College of Engineering*
JAMES C. MOUZON, Ph.D., *Associate Dean of the College of Engineering*
WALTER J. EMMONS, B.S., A.M., *Associate Dean Emeritus and Secretary Emeritus of the College of Engineering*
ARLEN R. HELLWARTH, M.S., *Assistant Dean and Secretary of the College of Engineering*
RAYMOND E. CARROLL, B.A., *Assistant to the Dean*
ROBERT H. HOISINGTON, M.S., *Assistant to the Dean*
IRA K. MCADAM, B.S.E. (M.E.), *Assistant to the Dean*
JOHN G. YOUNG, B.S.E. (M.E.), *Assistant to the Dean*

## General Information

Engineering is the profession that applies the laws of physical science to the efficient and economic conversion of natural resources for the benefit of man.

To design and produce the structures, machines, and products of industry requires the application of scientific and mathematical knowledge, the utilization of natural resources and capital, and the management of men.

The engineer is generally a practitioner. He brings to bear on each problem all available science and experience or judgment to arrive at the best or most economical solution. He combines knowledge of what to do and how to do it with understanding of why he is doing it and of the significant results that he may expect of his actions. He becomes not only an interpreter of science in terms of material human needs but also a manager of men, money, and materials in satisfying these needs.

An ever-present challenge in engineering work is to search for something better. The successful engineer is never satisfied with the existing design. He uses his ingenuity further to improve quality or performance, to increase efficiency, to decrease cost, or to facilitate production and construction. Often motivated by competition, he strives for some optimum goal that will reward him with new and exciting opportunities for service.

The educational objective of the College of Engineering is to prepare its students to take positions of leadership commensurate with their abilities in a world where science, engineering, and human relations are of basic importance. The programs are specially planned to prepare them, according to their aptitudes and desires, to become practicing engineers, investigators, administrators, or teachers. The useful knowledge and mental discipline gained from such educational programs, however, are so broad and fundamental as to constitute excellent preparation for other careers.

Some qualified graduates will continue their formal education at the graduate level leading to a master's or doctor's degree. One of the opportunities for continued growth and development after college is registration as a professional engineer. In each state of the United States, after a specified length of experience, usually four years, the young engineer may pass qualifying examinations to attain this status.

The student will have the opportunity of associating with teachers who have professional experience, gained through research, consultation, and engineering employment. The University of Michigan believes that engineering experience improves the ability of teachers, both in the classroom and laboratory. Members of the faculty are encouraged to be active in professional practice in order to keep informed on new developments in their respective fields. Facilities at the University provide for its teachers not only an atmosphere of research but also convenient opportunities for continuing their professional development, increasing their understanding of the subjects taught, and passing on to their students the benefit of their investigations and firsthand experiences.

Teaching is often at its best when the student and teacher work together in developing new relationships of a fundamental nature, or better and more economical ways of applying scientific knowledge to the problems of industry and the public welfare. Graduate and undergraduate students are given an excellent opportunity to take part in such activities in the well-equipped engineering laboratories, at several field locations, and on a variety of engineering projects.

An excellent criterion for predicting success is good performance in high school, particularly in mathematics, science, and English. Other important factors are: an interest and curiosity in the "why" of things, an ability to visualize objects well in three dimensions, sound habits of work and study, a persevering spirit, and good health. A serious mistake is frequently made in regarding manual dexterity, or an interest in mechanical things, as the only standards for judging abilities important for high achievement in the profession of engineering.

The choice of a career is a most important one and should be based on sound and complete information. If at all possible, a prospective student should discuss his interests and abilities with practicing engineers. In many communities, professional engineering societies provide counseling services. The Admissions Office of the University and the officers and program advisers of the College of Engineering will gladly be of service in assisting students with career planning.*

Successful completion of undergraduate work leads to the degree of Bachelor of Science in Engineering. The fourteen programs offered by the College of Engineering cover a wide spectrum; they are listed in the Contents. A student should select a program near the completion of his second semester, or of approximately 30 credit hours, as explained under Freshman Program.

## ACCREDITATION

The several degree programs have been examined by the Engineers' Council for Professional Development. The following have been accredited: Aeronautical, Chemical, Civil, Electrical, Engineering Mechanics, Industrial, Materials, Mechanical, Metallurgical, Naval Architecture and Marine Engineering, Physics, and Science.

## FACILITIES

The physical facilities of the University for instruction, housing, health care, recreation, physical education, and athletic activities are described in the bulletin *General Information,* available upon request.

The **West Engineering Building** (1904) contains the offices of the College, sanitary and structural laboratories of the Civil Engineering Department; solid mechanics, fluid mechanics and dynamics laboratories of the Engineering Mechanics Department; drafting, computing, and design rooms of the Engineering Graphics Department and other departments; 360-foot ship model towing tank used by the Naval Architecture and Marine Engineering Department for hydrodynamic studies on ship models; and complete demonstration facilities and computers for courses offered by the Industrial Engineering Department.

Directly across the street, the **East Engineering Building** (1923) houses well-instrumented machine-tool and machinability laboratories; gaging and measuring laboratory of the Mechanical Engineering Department; foundry and melting laboratory; metalworking, welding, heat-treating, spectrographic (mass, infrared, ultra-violet, etc.), and metallographic laboratories; an X-ray laboratory for radiography and diffraction studies; an electron microscope; chemical, high-pressure, process dynamics, polymer, semi-

*A vocational booklet entitled *Engineering—A Creative Profession* may be obtained (25 cents per copy) from Engineers' Council for Professional Development, 345 East 47th Street, New York 17, N.Y. It answers many questions commonly experienced by high school students who are considering engineering as a career and describes in particular several general fields of the engineering profession.

conductor, plasma, liquid metals, nuclear metallography, and measurements laboratories of the Chemical and Metallurgical Engineering Department; the soil dynamics laboratory of the Civil Engineering Department; and the highway and soil mechanics laboratories of the Michigan State Highway Department, which are also used for instruction by the Civil Engineering Department.

The **East Engineering Addition** (1947) contains two subsonic wind tunnels, supersonic jet, structures, propulsion, and instrumentation laboratories of the Aeronautical and Astronautical Engineering Department; energy conversion and power systems, communications, electronics, adaptive and control systems, computers, space and electron physics research, radiation and propagation, and solid-state devices laboratories of the Electrical Engineering Department; and the meteorological laboratories for the Meteorology and Oceanography Department.

The **Engineering Library,** located on the third floor of the Undergraduate Library, is one of the more than twenty divisional libraries in the University Library system. Its collection of approximately 134,000 volumes covers all fields of engineering. The library subscribes to almost 900 periodicals and maintains large collections of pamphlets, technical reports, and industrial catalogues.

The Engineering Library also maintains two special collections: the **Phoenix Library,** located in the Phoenix Memorial Laboratory on the North Campus, containing an AEC depository collection of approximately 86,000 reports as well as almost 3,500 volumes on atomic energy; and the **Transportation Library,** containing more than 122,000 volumes on all phases of the subject of transportation.

Trained staffs are available to assist the student in making effective use of these libraries, as well as of the University Library system as a whole.

The **North Campus** now houses the following laboratories for instruction and research:

The memorial **Mortimer E. Cooley Building** (1953) provides space for an auditorium and conference rooms, and for an electronic systems and circuits laboratory of the Electrical Engineering Department.

**Phoenix Memorial Laboratory** (1955) and the accompanying Ford Nuclear Reactor (1956) provides facilities for the Nuclear Engineering Department as well as for various University research activities associated with peaceful uses of atomic energy.

The **Aeronautical Engineering Laboratory** (1957) provides hypersonic, supersonic, and low-turbulence wind tunnels and propulsion laboratories for studies by the Aeronautical and Astronautical Engineering Department in aerodynamics and propulsion.

The **Automotive Engineering Laboratory** (1957), generously supplied with equipment by the industry of the state, provides laboratories for the Chemical and Metallurgical, Electrical, and Mechanical Engineering departments for studies of combustion, mechanical and electrical systems and for work on engines, chassis, and suspension systems. It also provides space for the Civil and Nuclear Engineering departments.

The **Fluids Engineering Laboratory** (1958) provides space for all departments in the study of fluid-flow problems; for the Mechanical Engineering Department on heat transfer, thermodynamics, and power generation studies; for the Chemical Engineering Department on process operation and heat transfer; for the Electrical Engineering Department on plasma engineering; for the Nuclear Engineering Department in the areas of nuclear measurements and analog computer applications; and for the Engineering Mechanics Department research in the basic mechanics of fluids.

A **Magnetofluiddynamics Laboratory** (1962) is jointly used by the Aeronautical and Astronautical, Electrical, and Nuclear Engineering departments. It contains a unipolar generator with a capability of a maximum of 300,000 amperes over a period of five milliseconds. The laboratory provides facilities for plasma, thermonuclear, hypersonic velocity, and high-density air-chamber studies.

The **Computing Center** provides an IBM 7090 and two IBM 1401 computers for use by the educational and research programs of the University. Engineering students prepare problems for solution on this equipment as a regular part of more than sixty different courses. In addition, several smaller digital computers and many analog computers are located within the College of Engineering. Every student may expect to become familiar with the theory and application of modern computing methods during his course of study.

**Camp Davis** is situated in the valley of the Hoback River, twenty miles southeast of the city of Jackson, Wyoming, and seventy-five miles south of Yellowstone National Park. The University of Michigan was the pioneer in the establishment and maintenance of a camp for field work in surveying. The first camp was organized in 1874 under the supervision of the late Professor J. B. Davis. Several sites were occupied in Michigan until 1929 when the University purchased land for the location of the present camp. The elevation of the camp, more than six thousand feet above sea level, the nature of the surrounding area, and the climate combine to make the location nearly ideal for summer instruction in surveying and geology.

Buildings at the Willow Run Airport contain the **Lake Hydraulic Laboratory**, equipped with a large wave tank and wave-making machine and the instruments required for the study of problems arising from the action of water along shores; the **Concrete Research Laboratory**, established to study new developments in concretes; and a **Propulsion Laboratory**, equipped with stands for testing various types of jet and rocket motors.

A **radio telescope** (1959), located in the Radio Astronomy Observatory situated sixteen miles from Ann Arbor, provides opportunities for electrical engineering students interested in the engineering aspects of radio astronomy.

## CO-OPERATIVE PROGRAMS WITH INDUSTRY

In certain fields a desirable combination of theory and practice is available, to a limited extent, through the medium of co-operative courses with industry. To be eligible for acceptance in a co-operative program a student must have completed a substantial part of his program, at least one year in residence, with good grades. He must be acceptable to the company with which he plans to work. He will devote alternate semesters to study at the University and in the employ of the company. He will receive regular compensation for his work and will be subject to the regulations of the company by which he is employed. When accepted in a co-operative program, he is expected to continue in it until he graduates or leaves the University.

Co-operative programs have been established with several companies and public organizations. The College is willing also to consider the proposals of students who find it possible to arrange for alternate semesters of study and work with any organization offering opportunities for experience which will contribute to their educational progress.

Credit is not granted for work experience, but a co-operative program, when approved, is entered upon the student's official record.

## DEARBORN CAMPUS

The Dearborn Campus, an integral part of The University of Michigan, provides the newest and one of the most unusual educational opportunities of the University. It offers a full-fledged co-operative program in electrical, industrial, mechanical engineering, and engineering mathematics. Students seeking admission must have completed the requirements of the first two years for the program elected either on the Ann Arbor campus, at an accredited junior college, or at another accredited college or university. A student desiring further information should write: Admissions Office, Dearborn Campus, 4901 Evergreen Road, Dearborn, Michigan.

## PLACEMENT

The College of Engineering considers the proper placement of its graduates to be very important, since it is recognized that the first years of professional experience are of great significance in developing the full capabilities of the young engineer. For this reason the College provides an engineering placement service for both students and alumni in Room

128H, West Engineering Building. This service includes the arranging of employment interviews on campus, the providing of career and placement information through counseling and published material, and the distribution of announcements of openings received by mail.

Meetings for students are also conducted by the placement service at the beginning of each semester on subjects of placement interest, such as the nature and availability of engineering opportunities, techniques for effective interviewing and plant visits, and considerations of engineering practice and professional development.

Many employers of engineers provide opportunities for students, particularly after their third year in college, to work in an engineering environment during summer vacation.

## EXTRACURRICULAR OPPORTUNITIES

Students at The University of Michigan enjoy many privileges outside of their classes as indicated in the bulletin *General Information.* Living a full life is an art, acquired by practice. The *Michigan Technic,* debating societies, orchestras, bands, glee clubs, sports groups, and other organizations provide excellent opportunities for self-development. They constitute an important part of the University life, and engineering students are encouraged to take an active part in them after the day's work is well done.

The following organizations, many of them related to scholastic or professional interests, are among those available to students of the College of Engineering upon meeting the respective requirements for membership or participation.

**Alpha Pi Mu,** national industrial engineering honor society
**American Institute of Chemical Engineers,** student chapter
**American Nuclear Society,** student branch
**American Rocket Society,** student branch
**American Society of Civil Engineers,** student branch
**American Society of Mechanical Engineers,** student branch
**Chi Epsilon,** national civil engineering honor fraternity
**Engineering Student Council**
**Eta Kappa Nu,** national electrical engineering honor society
**Institute of Electrical and Electronics Engineers,** student branch.
**Michigan Metallurgical Society**
**Michigan Technic,** a monthly magazine containing articles on technical subjects and other matters of interest to the College, staffed by engineering students
**Phi Eta Sigma,** national honor society for freshman men
**Phi Kappa Phi,** national honor society for seniors of all schools and colleges
**Pi Tau Sigma,** national mechanical engineering honor fraternity
**Quarterdeck Society,** honor-technical society for students in naval architecture and marine engineering

**Sailing Club**, an organization for dinghy sailing, iceboating, intercollegiate competition
**Scabbard and Blade**, national ROTC honor fraternity
**Sigma Xi**, a national society devoted to the encouragement of research
**Society of Automotive Engineers**, student branch
**Society of Women Engineers**
**Tau Beta Pi**, national engineering honor society
**Triangles**, junior honor society
**Vulcans**, senior honor society

Students interested in exploring other opportunities may review a complete list of campus organizations in the Office of Student Affairs, 2011 Student Activities Building.

## SCHOLARSHIPS, FELLOWSHIPS, PRIZES, LOANS, AND EMPLOYMENT

Numerous scholarships, fellowships, and prizes, as well as loan funds, are available to engineering students. A list of these, with the conditions governing them, appears in the special bulletin *University Scholarships, Fellowships, and Prizes,* which is available upon request to the Office of Student Affairs, Student Activities Building. March 1 is the deadline for applying for scholarships.

The Committee on Scholarships and Loans of the College has under its jurisdiction those scholarships and aid funds which have been established for the special benefit of undergraduate students in engineering. In general, such assistance is awarded on the basis of high scholastic performance and of demonstrated need. Applications may be addressed directly to this committee at the office of the Dean.

A number of qualified seniors are employed each semester as student assistants for assigned work in the several departments. Qualified graduate students are frequently provided assistance to continue their studies toward master's or doctor's degrees either through fellowships or a variety of employment opportunities in teaching or research.

## VETERANS

The University of Michigan welcomes veterans and provides information, guidance, and counseling to those eligible for educational benefits under Public Laws 550, 634, and 894.

All students who are eligible for and elect to receive education and training benefits while attending the University are required to register with the Veteran Affairs Office, 2059 Administration Building, as an integral part of the registration process.

## FEES AND DEPOSIT

Semester and summer session fees, subject to change without notice, are as follows:

### SEMESTER FEES

| | MICHIGAN RESIDENTS | NON-RESIDENTS |
|---|---|---|
| Freshman-Sophomore | | |
| Eight hours or more | $140 | $450 |
| Six or seven hours | 115 | 365 |
| Four or five hours | 85 | 285 |
| One to three hours | 60 | 190 |
| Junior-Senior | | |
| Eight hours or more | 155 | 480 |
| Six or seven hours | 120 | 385 |
| Four or five hours | 90 | 290 |
| One to three hours | 65 | 205 |
| Graduate (Rackham) | | |
| Eight hours or more | 175 | 500 |
| Six or seven hours | 145 | 415 |
| Four or five hours | 110 | 315 |
| One to three hours | 75 | 215 |

### SUMMER SESSION FEES

| | | |
|---|---|---|
| Freshman-Sophomore | | |
| Five hours or more | 80 | 235 |
| Four hours | 60 | 190 |
| Three hours | 55 | 165 |
| Two hours | 45 | 135 |
| Junior-Senior | | |
| Five hours or more | 90 | 250 |
| Four hours | 70 | 200 |
| Three hours | 60 | 170 |
| Two hours | 50 | 140 |
| Graduate (Rackham) | | |
| Five hours or more | 100 | 260 |
| Four hours | 80 | 210 |
| Three hours | 70 | 180 |
| Two hours | 60 | 150 |

Students enrolled as special students or guest students in the College of Engineering will be assessed the junior-senior fees. Any question on residence regulations may be referred to the Assistant Dean.

Semester fees are payable prior to registration, at registration, or in installments during the semester. The number and dates of the installments will be specified in advance for each semester. Requirements on the enrollment deposit are stated below.

Students are urged to provide themselves with money orders or bank drafts to cover semester fees. For the convenience of students, the Cashier's Office will cash or accept, in payment of semester or other University fees, money orders or bank drafts. Personal checks will not be cashed but will be accepted for the exact amount of fees.

Semester fees are the student's contribution to the cost of class instruction, library services, physical education privileges, membership in the Michigan Union or Michigan League, and medical attention from the University Health Service in accordance with regulations of the Health Service as given in the bulletin *General Information.*

Foreign students who are not provided with health-hospitalization insurance by their sponsors are required to purchase Student Group Health Insurance. The cost of this coverage (approximately $25) *must* be paid at the time of registration. This coverage extends for a full twelve months.

**Indebtedness to the University.** Proper observance of financial obligation is deemed an essential of good conduct, and students who are guilty of laxness in this regard to a degree incompatible with the general standards of conduct shall be liable to disciplinary action by proper University authorities. Students shall pay all accounts due the University in accordance with regulations set forth for such payments by the Vice-President in charge of Business and Finance.

When a student's account shows indebtedness, academic credits are withheld, most recent grades are not released, no transcript of academic record will be issued, nor will future registration be permitted.

**Enrollment Deposit.** In order to manage its over-all enrollment more efficiently and to guarantee each bona fide student a place in that enrollment, the University requires a $50 enrollment deposit for all students, including special nondegree candidates.

Once established, the $50 remains on deposit until the student applies for refund, thereby relinquishing his enrollment privilege for subsequent semesters.

*Establishment.* Each newly admitted student, and each student returning after an absence of one or more semesters is required to pay this $50 enrollment deposit in accordance with instructions provided by his admission office. Once established, this deposit is nonrefundable until after enrollment. "Summer only" students are not required to establish this deposit. The deposit must be made in the name of the student and, when applicable, will be refunded to the student.

*Refund.* A student terminating enrollment at the end of a semester *must make written request* at the office of Registration and Records, 1513 Administration Building, for refund on or before the dates given as follows:

December 1—Fall semester student not returning for the spring semester.
July 1 —Spring semester student not returning for the fall semester.
August 1 —Summer semester student not returning for the fall semester.

Payment of enrollment deposit refund, less any debts to the University, will be made by check. Approximately 30 days are required to process refunds.

A student who disenrolls during a semester should request refund prior to leaving the University. Any student disenrolling or failing to re-enroll due to University action may apply for refund of this deposit. Such requests should be made *in writing* within 30 days after the University's action.

*Forfeiture.* The Enrollment Deposit is subject to forfeiture for any student failing to enroll before the second week of classes. Failure to apply for refund on or before specified dates and voluntary failure to enroll for the next succeeding semester (excluding summer) will result in forfeiture of this deposit.

*Right of Appeal.* In case of forfeiture, the student may exercise the right of appeal through the Office of Registration and Records to the Enrollment Deposit Committee, whose decision is considered final.

*Re-establishment of Enrollment Deposit.* A student must obtain written approval from his admission officer to re-establish the $50 enrollment deposit. Questions and correspondence concerning the enrollment deposit should be directed to the Enrollment Deposit Section, Office of Registration and Records.

# Admission

Applicants for admission should be at least sixteen years of age and officially recommended graduates of accredited high schools. They must present acceptable evidence of good moral character, and must satisfy requirements as explained under Health Service Approval. General policies and requirements are stated in the bulletin *General Information.*

Applications for admission in September should be submitted by the preceding March 1 to receive equal consideration with other applicants. However, qualified students who seek admission after this date will always be given consideration. Since there is no application fee, no money should be sent when making application for admission.

## ADMISSION AS A FRESHMAN

High school students who have begun the senior year are invited to write to the Director of Admissions, Student Activities Building, for application forms and instructions for admission to the College of Engineering. Early application will make it possible to inform students of the probability of their admission and to call attention to any requirements still unfulfilled. Admission, when granted to a high school student, is contingent upon satisfactory completion of his high school program.

Both the Office of Admissions and the College of Engineering welcome the opportunity to interview prospective freshmen, but recommend that appointments be arranged in advance.

### CRITERIA

The admission requirements are designed to ensure that each student who is granted an opportunity to enroll in the College of Engineering has aptitude for the profession of engineering as well as intellectual capacity combined with the necessary interest and motivation to pursue his college work successfully. Students' qualifications in these respects vary widely, and from long experience it is evident that no single criterion is sufficient to judge the ability of every applicant.

The College, therefore, takes into account each of the following four criteria in arriving at a decision for each applicant: subjects studied in high school, scholastic performance, aptitude test scores, and high school recommendation.

**1. Subjects Studied in High School.** A unit for admission is defined as a course covering a school year of at least 120 sixty-minute hours of classroom work. Two or three hours of laboratory, drawing, or shop work are counted as equivalent to one hour of recitation.

Applicants for admission as freshmen without entrance deficiency must present a minimum of fifteen units of acceptable high school credit in accordance with the following schedule:

| | |
|---|---|
| *English* | |
| At least three units are required | 3 |
| *Mathematics Group* | |
| At least three and one-half units are required, including algebra, two units; geometry (including some solid geometry), one unit; trigonometry, one-half unit | 3½ |
| *Science Group* | |
| Two units are required. These should consist of one unit of physics and one unit of chemistry but botany, zoology, or biology may be offered. | 2 |
| *Required Group* | |
| Three units are required from a group consisting of foreign languages, botany, zoology, biology, history, economics, or additional English, mathematics, or chemistry. Not less than one full unit of a foreign language will be accepted | 3 |
| The remaining units required to make up the necessary fifteen units may be elected from among the subjects listed above and any others which are counted toward graduation by the accredited school | 3½ |
| Total | 15 |

Four units of English, four units of mathematics, one unit of chemistry, and one unit of physics should be presented whenever feasible. With excellent preparation, some acceleration is possible at the University, as stated under "Planning the Student's Program."

An applicant who does not meet the preceding requirements for admission is advised to consult the Director of Admissions concerning his particular problem. Deficiencies may be removed before the anticipated date of entrance. When conditions warrant such action, provisional admission may be granted if not more than two units are lacking.

2. **Scholastic Performance.** The student's grades—particularly in English, mathematics, and science—together with his standing in his class, are considered important in determining eligibility for admission to the study of engineering. Interest and high achievement in these subjects will also help the student to decide whether or not he is making the right choice of a career, and to predict his likelihood of success in the engineering profession.

3. **Scholastic Aptitude Test.** Applicants are required to take during their junior or senior year in high school the College Entrance Examination Board Scholastic Aptitude Test (SAT).

When a senior desires a decision before the SAT test results are known, preliminary admission may be made if other acceptable test data are submitted to the Director of Admissions along with his application.

For information and time schedules on the Scholastic Aptitude Test, the student should consult his high school counselor or write to College Entrance Examination Board, Box 592, Princeton, New Jersey.

4. **High School Recommendation.** A statement by an authorized representative of the applicant's high school is required, relating to the character and seriousness of purpose of the applicant, his interests and attainments (both scholastic and extracurricular), his intellectual promise, and his potential for success. Such information provides additional background that may not be evident from the other criteria listed above.

## ADVANCED PLACEMENT

Many high schools throughout the country are offering work of such caliber that an incoming freshman may receive college credit for some subjects provided he has performed satisfactorily on Advanced Placement Program examinations conducted nationally by the College Entrance Examination Board. Such a student may significantly accelerate his education or he may enrich his stay in the College of Engineering by covering more material than does the normal student.

For information and time schedules on the tests referred to above, write to College Entrance Examination Board, Box 592, Princeton, New Jersey.

High school graduates desiring to be excused from taking courses in engineering graphics may be required to pass a comprehensive examination and to submit for approval appropriate drawings completed previous to entrance.

## ADMISSION WITH ADVANCED STANDING

An applicant desiring to transfer from an approved college in the United States with advanced credit should write to the Assistant Dean, College of Engineering, for an application form and instructions. He will be required to arrange for an official transcript of both his secondary school and college work, together with evidence of honorable dismissal from his college. This applies also to students planning to transfer from another unit in the University.

For admission without deficiencies, the applicant must satisfy the requirements for admission from high school as stated under Admission as a Freshman. The college transcript must list the subjects studied, the number of credit hours and grades earned in each subject, and the basis upon which grades are assigned. Results of any aptitude tests that were taken in high school or college are helpful.

The history of an applicant must demonstrate that he has the ability to meet the requirements of the College of Engineering for a Bachelor of Science in Engineering degree. An over-all scholastic average satisfactory for good standing at his previous institution may not in itself be sufficient. The grades earned in subjects related to the program elected by the applicant will be taken into account in judging his ability to succeed. As a minimum requirement, his scholastic record as interpreted by the College of Engineering must be such that he would be considered in good standing if his work had been taken at this College.

**Program with Basic Courses Taken in Another Institution.** Basic pre-engineering courses in English, mathematics, chemistry, and physics are offered by many liberal arts colleges and community or junior colleges. Generally, such courses are offered as a complete two-year program designed to meet the requirements for study at the professional level in many engineering colleges (e.g., a mathematics sequence requiring four semesters or six quarters). While a student will be considered for admission with any amount of college credit, he should weigh the advantages of completing the required basic program before seeking a transfer.

In many institutions a student is able to satisfy the requirements of physical education, economics, and nontechnical subjects; he may also be able to complete his work in engineering graphics and engineering materials and to start engineering mechanics if his institution offers adequate instruction in these fields.

A student in another college or university who desires to transfer to the College of Engineering should examine carefully the program which he plans to elect at this College and arrange his work accordingly. Questions pertaining to choice of field or program and course elections not answered in this *Announcement* may be addressed to the program adviser in the program he wishes to elect. Other questions of a general nature and those relating to admission requirements should be addressed to the Assistant Dean.

**Combined Programs With Other Institutions.** The College of Engineering co-operates with other institutions in providing an opportunity to earn two bachelor's degrees (A.B. or B.S. and B.S.E.) in approximately five years by satisfying the requirements for both degrees. Representative of institutions providing this opportunity are: Albion College, Alma College, Calvin College, Central Michigan University, Eastern Michigan University, Emmanuel Missionary College, and Kalamazoo College. Normally an interested student would enroll at one of these institutions for his first three years and include in his elections a pre-engineering program that, under conditions of satisfactory performance, will transfer as substantially equivalent to two years of the requirements of the College of Engineering.

In co-operation with the College of Literature, Science, and the Arts of the University, combined programs are offered in the fields of chemical and civil engineering. Each of the programs generally requires five years and one summer session for completion and leads to baccalaureate degrees in both the College of Engineering and the College of Literature, Science, and the Arts. Requirements are stated on pages 48 and 53. Consideration is being given by the two Colleges to a proposal to extend this opportunity to students in other programs.

**Admitting Graduates of Other Colleges.** A graduate of an approved college may be admitted as a candidate for a degree in engineering. The official transcript must certify the date of graduation. Upon the satisfactory completion of the prescribed courses, covering at least two semesters' enrollment and a minimum of 30 hours of credit, the student will be recommended for the degree Bachelor of Science in Engineering.

**Adjustment of Advanced Credit.** An appraisal of the previous record of a student transferring from a college or university located in the United States will be made, usually at the time of admission, to indicate tentatively the number of hours of credit that will be allowed toward a B.S.E. degree in the program specified by the applicant. This appraisal is subject to review by representatives of the several teaching departments involved, and by the student's program adviser; the adjustment may be revised if it develops that the student is unable to continue successfully with his election because of an inadequate preparation. In general, credit will not be allowed for a course with a D or equivalent low grade. Class standing is determined by the number of credit hours transferred. (See under Class Standing).

In general, only those semester hours presented that contribute to the completion of the student's degree requirements will be recorded on his academic record. Grades earned in the courses transferred are not recorded, and the student's grade-point average is determined solely by the grades earned while he is enrolled in this College.

Credit for experience is not granted. When experience in industry closely parallels the content of a required course, however, the student may be excused by his program adviser from taking such course.

If at any time a transfer student has any question regarding the adjustment of his credit, he should consult the Office of the Assistant Dean.

## STUDENT NOT A CANDIDATE FOR A DEGREE

**Special Students.** A qualified candidate beyond high school age may be admitted as a special student in order to enroll in appropriately selected college courses without working for a degree.

Request for admission as a special student and supporting evidence of qualifications should be addressed to the Assistant Dean. Previous education, experience, and age will be taken into account in judging fitness for success in engineering studies. Admission and program of study are subject to the approval of the program adviser of the program to be elected.

A qualified college graduate may be admitted as a special student to take courses for which his preparation is sufficient.

To remain eligible for continued enrollment, a special student is required to meet the same academic standards as a degree candidate. He may later become a candidate for a dgree if he meets the regular requirements for admission.

A student who is a candidate for a degree cannot transfer to a special status.

**Guest Students.** Students regularly enrolled in another college are permitted to elect appropriate college courses as guest students. They must apply for enrollment before the beginning of each session they desire to attend.

## FOREIGN STUDENTS

Foreign students whose native language is other than English are required to complete basic college subjects (English, mathematics, chemistry, physics, engineering graphics) before applying to the Assistant Dean for admission to the College of Engineering; they must also meet prescribed standards of proficiency in English. For many students these requirements may be met at a minimum of expense by enrolling in a home college for a period of two years. Others may prefer to enroll in a liberal arts or engineering college in the United States for their basic college subjects before seeking transfer; this provides the advantages to the student of becoming accustomed to the educational system of this country and of improving his proficiency in English.

An applicant must submit an official copy in English of the scholastic record of his secondary and college education, showing the grade (or mark) earned in each course together with maximum and passing grades.

Since English is the language of instruction in the United States, a foreign student attends classes with students whose background and education have been in English, and he must maintain the same scholastic standards. In order that he may know that his control of the English language is adequate to carry on his studies without serious handicap, each student whose native language is not English is required to pass an English proficiency examination before he is admitted. This test is prepared and administered abroad by the English Language Institute of the University. If the applicant is informed that his scholastic record is satisfactory, he will then be instructed to make arrangements for the test with the English Language Institute. The charge for this test taken abroad is $10.00, or its equivalent in the local currency.

For students who need to improve their control of English considerably before beginning regular college studies, the English Language Institute offers the eight-week Intensive Course in English (ELI 100). For further information, write to the English Language Institute, 2001 North University Building, Ann Arbor, Michigan.

A foreign student granted entry into the United States by virtue of admission to another institution of higher education is expected to complete one academic year of study at that school. When a student wishes to transfer to this College, he is encouraged to submit an application for admission with advanced standing during the final semester or term of enrollment at the institution that issued the initial I-20 Form.

It is generally desirable that a foreign student elect a rather light schedule of studies for the first semester enrolled in the College of Engineering because he is living in an unfamiliar environment and is studying under an educational system which may be new to him. If he fails in his studies and if, in the judgment of his instructors and adviser, his failure is due primarily to his lack of proficiency in the English language, his record will be disregarded and he will be required to pursue additional remedial study of English as may be deemed necessary before resuming his professional studies.

For statement on health insurance requirements for foreign students, see Fees and Expenses.

**International Center.** A foreign student with financial, immigration, housing, or personal adjustment problems is assured of careful and understanding counseling at the University's International Center. Students also have opportunities to plan and participate in social activities under the sponsorship of the Center.

## Academic Counseling

To plan his educational program wisely and efficiently each student should understand his own aptitudes, abilities, and interests and their relationship with his future. A student with some question in this regard, or any other personal problem on which he feels the need of counseling, is urged to consult University people who are qualified to help him.

Engineering students who are uncertain regarding procedures, or who have special problems, may seek advice from the Office of the Assistant Dean, 259 West Engineering Building.

**Orientation.** All new students, both freshmen and those transferring from other colleges, are assigned to small groups which are guided through the various steps of orientation. These details include testing, a call at the Health Service, preparation of the student's identification card, consultation with academic counselors, selection of courses, assignment of fees, and attendance at the necessary orientation group meetings.

Freshmen entering in the fall semester are encouraged to come to the campus during the summer for a two-day orientation schedule. At the same time, parents are invited to attend a program particularly arranged for them.

Each transfer student is instructed on procedures relating to the adjustment of transfer credit from other colleges.

**Academic Counseling for Freshmen.** Freshman counselors, consisting of a group of well-qualified members of the professional teaching staff, are available in a central freshman counseling office for interviews at all times throughout the year.

Each entering freshman meets with a counselor to determine his schedule of courses for his first semester. The necessary counseling takes into account his entrance credits, level of high school achievement, test results, and other information made available to the counselor.

Developing self-reliance and ability to appraise his own performance and intellectual growth is an important part of the student's education. Nevertheless, freshmen are encouraged to consult with counselors at any time during the year concerning their career plans and academic programs and to discuss any matter of interest or concern. A particularly appropriate time to examine progress is at the time of the midsemester grade report.

**Program Adviser.** At the beginning of each of the statements on the fourteen undergraduate programs (given later in this *Announcement*) is the name of a member of the faculty designated as program adviser. This person is available primarily to counsel students above the freshmen level on their academic program and other matters such as changes in objectives and choices of subject electives. Program advisers will also assist each student with career planning and other decisions that are necessary to make a proper selection of a particular program. A freshman who needs additional help in this respect may attend group meetings or, by appointment, consult with the several program advisers.

Certain authorities, as covered under Election of Studies and Grades and Scholastic Standing, are specifically assigned to program advisers.

**Academic Counselor.** Program advisers are assisted by associates on the faculty according to the needs of the respective programs. As academic counselors, they assume responsibility for elections counseling as covered under Election of Studies or as specifically delegated.

**Other Counseling Services.** In addition to academic counseling, the University provides specialized services to meet the various needs of students. A counseling service is available in the Bureau of Psychological

Services for those needing more specialized assistance to clarify their educational and vocational objectives. For those students experiencing personal difficulties requiring the assistance of specially qualified counselors, the Mental Health Clinic of the Health Service is available. Training in reading speed and comprehension is provided for students especially in need of such assistance. Remedial training in speech is offered by the Speech Clinic. The churches in Ann Arbor provide counselors on religious problems. The Office of Student Affairs provides counsel and assistance on housing, financial, employment, and other nonacademic problems. The men's and women's residence halls, accommodating freshmen and a large number of upperclassmen, maintain a staff of advisers and student assistants who help the student make an effective adjustment to the University community.

## Planning the Student's Program

By offering a variety of programs, the College provides opportunities for meeting the special needs and interests of each individual student. Students are admitted with varying degrees of ability and with differences in high school or other pre-engineering preparation. These variations, and the student's choice of an engineering field, necessitate considerable flexibility in arranging schedules and programs. Hence, every effort is made to plan a schedule for the newly admitted student so that his college experience will be more effective for him.

### FRESHMAN AND SOPHOMORE PROGRAM

The program for each freshman is planned with the objective of placing him in courses commensurate with his previous preparation and his ability, so that he may reach the level of attainment required for graduation as efficiently as possible. At the same time, his schedule should not include courses which the student is judged to be unable to handle successfully. The high school performance record and results of various tests will help in planning a program that meets these objectives.

Students are required to remove all admission deficiencies during their first year, unless granted an extension of time. A student who does not present three and one-half units in the mathematics group (see Admission as a Freshman) will find it to his advantage to remove the deficiency during the summer preceding the first semester of the freshman year.

Most courses have prerequisites (see Description of Courses). The completion of courses on schedule and with satisfactory grades is essential to the student's progress.

**Studies of the First Year.** The schedules for the first year will generally include courses from among the following subjects: mathematics, English, engineering graphics, chemistry, physics, and an elective subject in a nontechnical field. For courses common to all degree programs, see Undergraduate Degree Programs—Group A.

Physical education (twice a week through the year without credit in hours) is required of all first-year students unless enrolled in one of the three Reserve Officers Training Corps programs.

Opportunities are offered for reserve officer training in air, miltary, and naval science. Enrollment in one is not required, but those who choose to enroll are excused from taking physical education (see statement concerning conditions of voluntary enrollment under Reserve Officers Training Corps).

If Reserve Officers Training Corps enrollment is elected, hours of credit and the grades earned will be recorded and included in the computation of average grades. The only hours that may be applied to degree requirements are for those advanced courses in the third and fourth year that are permitted in the schedule of requirements of the respective programs.

While many variations in freshman schedules are possible, the following will serve as a guide to each student in planning his own personal program:

| FIRST SEMESTER | CREDIT HOURS | SECOND SEMESTER | | CREDIT HOURS |
|---|---|---|---|---|
| English 111 and 121 | 4 | English 112 | | 2 |
| Mathematics 115 | 4 | Mathematics 116 | | 4 |
| Chemistry | 4 or 5 | Physics 145 | | 5 |
| Eng. Graphics 101 | 3 | Eng. Graphics | 3 or 2 | 2 to 7* |
| *or* | | Chemistry | 4 | |
| Elective | 3 or 4 | Elective | 2 to 7 | |
| Physical Education | 0 | Physical Education | | 0 |
| *or* | | *or* | | |
| ROTC | 1 or 3 | ROTC | | 2 or 3 |

Usual combinations of the subjects listed above will result in a semester schedule with 15 to 18 hours credit. The appropriate number for each student will depend on a number of factors: past scholastic record, placement tests, extracurricular activities, and need for partial self-support through outside work.

**Studies of the Second Year.** A part of the schedule for the third and fourth semesters consists of the remainder of the Group A courses common to all fourteen programs:

| THIRD SEMESTER | CREDIT HOURS | FOURTH SEMESTER | CREDIT HOURS |
|---|---|---|---|
| Mathematics 215 | 4 | Mathematics 216 | 4 |
| Physics 146 | 5 | | |

*Explanations regarding the several possibilities or combinations in this group of subjects appear in the following discussions.

The remainder will be made up of appropriate courses from the list of professional and advanced subjects and electives (Group B) specified for the program selected by the student.

**Choosing One of the Degree Programs.** While the entering freshman does not need to select a specific field of engineering, there is some advantage in arriving at a decision early. He should consult with his freshman counselor, with program advisers, and others for assistance and counsel in planning his career. During the second semester, he will be asked to select the degree program in which he plans to graduate. From this point on, the degree programs differ in their requirements. The differences are not so pronounced, however, as to make difficult a transfer from one program to another in the second year should the student change his career plans.

**Opportunity to Attain Two B.S.E. Degrees.** Through careful planning of his course elections throughout his college enrollment, a student with interests in more than one field of engineering may work for two B.S.E. degrees concurrently. Inasmuch as he must satisfy the subject requirements of both programs as specified by the two program advisers, he will find that he can accomplish this in a minimum of time by starting his plans early. (See under Requirements for Graduation, paragraph 4.)

## VARIATIONS AND ACCELERATION POSSIBILITIES

The following discussions and outlines will serve as additional guides. They include a number of variations and possibilities for accelerating the progress of qualified students. A number of factors are taken into account, but other variations not covered here may be arranged in consultation with counselors and program advisers according to the needs and qualifications of each student.

**English.** English 111, Composition, and English 121, Speech, are generally prescribed for the first semester. A student who is considered to be unprepared for English 111 will be assigned first to English 110, Preparatory Composition, but may be advanced to English 111 if the instructor finds him able to meet the requirements of that course.

Generally, a student will take English 112 during the second semester and prior to electing courses from Group II. If a student has met the English 112 requirement during the first semester, or has been excused from the course on the basis of proficiency, he may elect a course from Group II during the second semester. Courses in Group I-A are also available to freshmen to satisfy part of the requirements for nontechnical electives. See pages 152 and 153.

**Mathematics.** The usual mathematics sequence of 115, 116, 215, and 216 provides an integrated sequence in college mathematics, sixteen hours credit, that includes analytic geometry, calculus, and elementary differential equations.

While most freshmen elect Mathematics 115 in their first semester, it is in the best interest of the student to place him in the mathematics course which most closely matches his previous preparation and his ability.

A student having an especially high level of mathematical preparation and ability may accelerate his training, with deeper penetration, through one of the honors-level sequences starting with Mathematics 185 or 195. See also the Unified Science sequence below.

A student who has completed a full year calculus course in high school, and whose preparation in this subject has been validated by College Board Advanced Placement scores, may receive eight hours credit in mathematics and be eligible for placement into Mathematics 215. Other students who have taken calculus in high school may receive appropriate advanced placement after taking a placement examination administered by the Department of Mathematics; information on this examination may be obtained from the Department of Mathematics Branch Office, 347 West Engineering Building.

The following outline will serve as a guide in determining the proper first elections in mathematics for freshmen:

| THOSE STUDENTS WHO: | ELECT | CREDIT HOURS |
|---|---|---|
| I. Are deficient in trigonometry. | Math. 107 (May accompany Math. 115) | 2* |
| II. Are deficient in both algebra and trigonometry. | Math. 105 | 4* |
| III. Have no deficiencies but whose high school record and SAT scores indicate possible difficulties in mathematics. | Math. 115 (A section meeting 6 times a week) | 4 |
| IV. Have no deficiencies and are qualified by high school record and SAT scores. | Math. 115 (A section meeting 4 times a week) | 4 |
| V. Qualify for Unified Science sequence (see below) or have special permission of the Department of Mathematics. | Math. 185 or 195 | 4 |

Transfer students from other colleges who have completed college algebra, and plane and solid analytic geometry without calculus, normally will be allowed six hours credit and will be required to take Mathematics 213 and 214 (five hours credit each) to complete the Group A requirements.

**Engineering Graphics.** The freshman schedule includes a three-hour engineering drawing course in the first semester, Engineering Graphics 101. The several programs vary with respect to additional requirements in en-

*While these two courses will not provide credit toward the student's degree, the grades will be used in computing grade point averages.

gineering graphics. The student should refer to Group B of the departmental program in which he plans to enroll and should consult with his counselor before electing further graphics courses. Graphics 101 is usually followed by Graphics 102, 3 hours credit, or Graphics 104, 2 hours credit.

**Chemistry.** Chemistry is not required as a science unit for admission, although it is strongly recommended.

A number of factors determine the proper elections in chemistry. These are best covered in outline form as follows:

| THOSE STUDENTS WHO: | ELECT | CREDIT HOURS |
|---|---|---|
| I. Have not had chemistry in high school (*a*) and who definitely plan to take succeeding chemistry courses for programs such as Chemical, Metallurgical, Materials, or Science Engineering; | Chem. 103 and 106 | 8 |
| (*b*) others | Chem. 103 and 105 | 8 |
| II. Have had chemistry in high school but do not qualify for Chemistry 107 or Unified Science sequence (*a*) and who definitely plan to take succeeding chemistry courses for programs such as Chemical, Metallurgical, Materials, or Science Engineering; | Chem. 104 and 106* | 8 |
| (*b*) others | Chem. 104 and 105* | 8 |
| III. Have shown proficiency in chemistry in high school and on chemistry tests. | Chem. 107 (given fall sem. only) | 5 |
| IV. Qualify for Unified Science sequence (see below) | Chem. 194 and 195 | 8 |

A student planning to elect a program requiring additional chemistry should refer to the schedule of the selected program and consult with the program adviser to determine the most suitable sequence of advanced chemistry.

**Physics.** Physics is not required as a science unit for admission, although it is strongly recommended.

The freshman schedule includes Physics 145 in the second semester. This course assumes knowledge of calculus and follows Mathematics 115. Transfer students placed in Mathematics 213 may elect Physics 145 concurrently. Physics 145 is followed by Physics 146, making a total of 10 hours.

Those students who qualify for Unified Science sequence will elect Physics 153 and 154 for a total of 8 hours (see below).

**Unified Science Sequence.** The Unified Science sequence consists of

*A student with a high record in Chemistry 104 may be invited to elect Chemistry 191, 5 hours, instead of Chemistry 105 or 106. This combination provides the student with additional background in chemistry and may permit him to take succeeding courses at a saving of credit hours.

special honors-level courses in introductory college mathematics, physics, and chemistry designed for students with strong backgrounds in science and mathematics who have demonstrated outstanding academic abilities in high school. These courses are taken in the following order:

| | |
|---|---|
| First Semester: | Math. 185 (4 hours) and Physics 153 (4 hours) |
| Second Semester: | Math. 186 (4 hours) and Chem. 194 (4 hours) |
| Third Semester: | Math. 285 (4 hours) and Chem. 195 (4 hours) |
| Fourth Semester: | Physics 154 (4 hours) |

An example of this sequence appears in the representative schedule for the Science Engineering program.

These courses emphasize the use of mathematics and laboratory experimentation in developing the fundamental principles and concepts of the physical sciences. In addition, they are highly integrated, with each course building on the material taught in all previous courses. This approach allows each subject to be treated in a more rigorous manner and at a more advanced level than would otherwise be possible, and it provides a superior background in science and mathematics that is especially valuable for students in engineering.

Because of their integrated character, these courses can normally be taken only in the order given above, and it is necessary for students to enroll in them as freshmen and to complete the full two-year sequence to obtain maximum benefit from them. In the College of Literature, Science, and the Arts, the Unified Science courses are part of the Honors Program, and only students qualifying for this program are selected for the Unified Science courses. Students of comparable ability are selected from freshmen entering the College of Engineering. Preliminary selection of students is made during the freshman orientation period by special counselors, based on the students' high school records and their scores on the various examinations. The final decision to elect the sequence is made by the student after consultation with these counselors. No student is required to elect these courses; conversely, students who do not meet the minimum standards for honors-level work at the time of admission will not be admitted to the sequence.

**Other Possibilities for the First-Year Schedule.** A student who satisfies his chemistry or engineering graphics requirements during his first semester has an opportunity to select appropriate hours from a number of subjects during his second semester. A student who plans to select a program requiring additional chemistry, should elect an appropriate chemistry course. If he plans to select the chemical or metallurgical engineering program, he may elect Chemical and Metallurgical Engineering 200.

Acceptable nontechnical subjects may be elected that will apply against the requirements for nontechnical electives in Group B. For example, see English, pages 152 and 153, Group I-A.

## TRANSFER STUDENTS

Students who transfer from another college enter with a wide variety of previous preparation. After tentative adjustment of advanced credit, usually they will be counseled as follows:

*a*) A student with less than 25 hours of credit applicable to an engineering degree will be assigned to a freshman counselor;

*b*) A student with 25 hours or more will be referred to the program adviser of the program he elects.

In any case, the student's courses for his first semester will be determined by this College's evaluation of his past work and by his program adviser. If he finds at any time during the first two weeks that he has not been properly classified, he should report immediately to his program adviser.

# Rules and Procedures

## HONOR CODE

"Honesty, justice, and courtesy form a moral philosophy which, associated with mutual interest among men, constitutes the foundation of ethics. As the keystone of professional conduct is integrity, the engineer will discharge his duties with fidelity to the public, his employers, and clients, and with fairness and impartiality to all."

In 1916, thirty years before this statement was published by the Engineers' Council for Professional Development and adopted as part of the Canons of Ethics by the national professional engineering societies, the students of the College of Engineering, with the approval of the faculty, established and adopted the following procedure:

All examinations and written quizzes in the College are held under the Honor Code, the object of which is to create the standard of honor which is essential to a successful engineer and a good citizen. Students are expected to uphold the code or declare their unwillingness to do so after having been duly instructed in all its rules. The instructor does not remain in the room during an examination. The students are placed upon their honor to refrain from all forms of cheating and to reprimand a fellow student who acts suspiciously and, in case he does not take heed, to report him to the Student Honor Committee. Every student must write and sign the following at the end of his examination paper, if he had not asked for an examination under a proctor:

*"I have neither received nor given aid during this examination."*

Either a student or the instructor may report a violation that is then investigated by the Student Honor Committee, which makes a recommendation to the faculty Committee on Discipline.

The principles on which the Honor Code depends for its success apply to all facets of a student's life on the campus. Enrollment in the College carries with it obligations in regard to conduct outside the classroom as well as inside and students are expected to conduct themselves in such a manner as to be a credit to themselves, to the University, and to the community.

## HEALTH SERVICE APPROVAL

Health Service approval is a prerequisite for final admission. This approval is granted when the report of a physical examination is submitted by a physician of the applicant's choice upon a form provided by the University. It is not intended to establish standards of physical requirements for admission and the nature of the physician's report will not affect the eligibility of the applicant. It is essential, however, that the Health Service be provided with information with respect to the physical condition of each student in the best interest of the student himself and his associates. Vaccination for small pox and tetanus is strongly urged.

Physical examinations are not required of those applicants who intend to enroll only for the summer session or who are on campus for limited periods.

All new students will report to the Health Service for a chest X ray as a part of the normal registration procedure.

Students who have been out of residence for health reasons will go to the Health Service for clearance, as will those students who have received notice that special Health Service approval is required for readmission.

Treatment by the Health Service of those students entitled to that service is optional on their part, except when in the opinion of the Director they may be a source of danger to student health. The type and amount of service is in conformity with the rules and regulations of the Health Service.

Foreign students should observe the regulation regarding health insurance under Fees and Deposit.

## PHYSICAL EDUCATION

Each student entering the University from a secondary school is required to satisfactorily complete a one-year course in physical education suited to his health condition, unless exempted by service in the Marching Band (one semester) or official freshman sports. A transfer student with less than sixty hours of advanced credit, and without a year of physical education elsewhere, will be required to elect one year of physical education at the University unless excused by the Health Committee.

Veterans who have completed a regular tour of duty (minimum of 20 months of service), or its equivalent, are excused from the regular requirements of physical education. Students who enroll in a Reserve Officers Training Corps also fulfill the requirements of physical education.

All *unexcused absences* must be made up. Health Service statements will be accepted only for illness of more than twenty-four hours. All excuses for absences from required physical education classes must be presented to the Waterman Gymnasium office for approval.

## ELECTION OF STUDIES

**Credit Hours.** A credit hour represents, generally, one hour of recitation or lecture per week for one semester, preparation for which should require two hours of study; generally, one period of laboratory work is considered equivalent to one hour of credit. (An explanation of the time requirement for graduation will be found under Undergraduate Degree Programs and Requirements.)

**Counselor.** The word "counselor" as used in the following rules means freshman counselor for freshmen and academic counselor for other undergraduates.

**Course Offerings.** The annual *Announcement,* and the *Time Schedule* prepared for each semester will serve the student as a guide in planning each semester's schedule.

The faculty reserves the right to withdraw the offering of any elective course not chosen by at least six persons.

**Program Selection.** A student is required to select his program of study during the second semester of his freshman year and is referred to the appropriate program adviser at the completion of approximately thirty hours of Group A credits. A tentative program established at this time, will be helpful as a guide to the student and his elections counseling through the completion of the student's degree requirements.

**Changing or Adding a Program.** When a student desires to change from one program to another, or to elect an additional program, he must consult the program advisers of the programs involved and obtain the necessary approvals on a form supplied by the Records Office.

**Election Considerations.** At any time, a student's elections must take into account his preparation (including deficiencies), demonstrated ability and performance, interests and career plans, extracurricular activities or part-time employment, and recommendations of the Committee on Scholastic Standing, when applicable.

Any student who fails to maintain a satisfactory proficiency in English in any of his work in the College of Engineering shall be reported to the

Assistant Dean. After consultation with the Department of English and the program adviser, the student may be required to elect such further work in English as may be deemed necessary.

**Work Load.** Unless approved by his program adviser (for freshmen, the Assistant Dean), a student may not elect courses (or change his elections) for which the total number of hours for a semester is less than twelve or more than eighteen, and for a summer session less than six or more than nine. A student should have a 3.0 average or more for the previous semester to be permitted to carry a semester load of more than eighteen hours.

A student may be required to drop part of his course work at any time he appears to be undertaking too much, or to take additional work if he is not carrying a sufficient work load. If he is required to work to support himself wholly or in part, he should elect a schedule of courses consistent with his ability to earn grades that qualify for graduation and at the same time retain his health.

**Classification and Registration.** Each semester, the Classification Committee will prepare necessary instructions to program advisers, counselors, and students relating to election of courses, classification (including assignment to sections), and registration.

**Change of Classification.** After a semester has begun, changing a section, and adding or dropping a course, can be made official only through use of "change of classification" form, and upon authorized approvals.

Any change of classification which changes a student's fee assessment must be reported by the student to the Assistant Dean.

**Dropping a Course.** During the first eight weeks of the semester, a course may be dropped without record when there is a justifiable reason, and when the student has the approval of his counselor after conference with the instructor in the course. See Work Load, above.

After the first eight weeks of the semester, a student must obtain the approval of his program adviser (or the Assistant Dean for freshmen) to officially drop a course; approval without grade of E will depend on satisfactory evidence of extraordinary circumstances.

A student enrolled in an ROTC program must have the approval also of the professor in charge of the unit before he can drop an ROTC course or relieve himself of the obligation he assumed when he enrolled in the program.

The grade for any course dropped without permission will be recorded as ED (unofficial drop) and computed as E in the averages.

**Substitution.** Substitution of a course for one which is a requirement for graduation must be approved by the program adviser of the student's degree program on a form available at the Records Office, and is subject to review by the Curriculum Committee.

**Electives.** In order that a student may explore areas other than his chosen field of engineering, he is required to complete a minimum number of credit hours of elective studies. For details, refer to Group B subjects, page 41.

A student may elect courses in addition to those required for his degree.

He may not register in the Engineering College and elect courses offered by another college if such elections do not contribute to a goal of a B.S.E. degree, except when approved by the Assistant Dean.

## ATTENDANCE AND ABSENCES

Regular and punctual attendance at classes is one of a number of expressions of interest, maturity, and devotion to recognized standards of conduct that contribute to the dignity of the profession. The reasons for good attendance should be obvious, and a student may expect unexcused absences to reflect in his final grade.

All students are required to account to their instructors for their absences. An instructor may report to the Assistant Dean when he considers that the number of absences of an underclassman is excessive, and he may require the student to present a written excuse approved by the Assistant Dean.

A student who has been absent from studies for more than one week because of illness or other emergency should consult his adviser to determine the advisability of reducing his elections.

A student with an unresolved problem related to absences may consult the Assistant Dean.

## EXAMINATIONS

Classes may be examined at any time, with or without notice, on any part of the work. An examination at the end of the semester is an essential part of the work of the course.

Any student absent from an examination is required to report to his instructor as soon thereafter as possible. If a student presents a valid excuse for his absence, he may take the examination at such time as may be arranged by the instructor.

## GRADES AND SCHOLASTIC STANDING

**Definitions.** The word "semester" includes summer session (unless otherwise indicated). Minimum full schedule is twelve (12) credit hours during a semester or six (6) during a summer session.

The semester grade-point average and the over-all grade-point average are computed for each student at the end of each semester and become part of his academic record. The grades are valued per credit hour on the basis of:

| | |
|---|---|
| A—excellent ........ 4 points | D—passed .......... 1 point |
| B—good ........... 3 points | E—not passed ....... 0 points |
| C—satisfactory ...... 2 points | |

The grade-point average is computed by multiplying the number of points corresponding to the grade earned in each course by the number of hours of credit for the course, and dividing the sum of these products by the total number of credit hours represented by all the courses elected. The word "average" is synonymous with grade-point average.

**Academic Record.** Each student's "Academic Record" is that cumulative record maintained by the Records Office of his courses elected, grades, averages, and other matters relating to his progress. A copy is given to the student's program adviser after each semester's grades and averages are recorded.

Upon request by the student at the Records Office, first copy of his academic record is provided without charge, and additional copies at $1.00 each except as restricted under "Indebtedness to the University."

**Good Scholastic Standing.** To be in good scholastic standing at the end of any semester, a student must have an average of 2.00 or more for the semester and an over-all average of 2.00 or more. (See Rules Governing Scholastic Standing below.)

In order to attain a B.S.E. degree, a student's final over-all average must be 2.00 or more for all courses taken while enrolled in this College.

Degree candidates who carry a full schedule and earn a 3.50 semester average or better, attain the distinction of the Dean's Honor List for the semester.

**Unsatisfactory Performance.** Three degrees of scholastic deficiency identify a student's unsatisfactory performance resulting from D and E grades: (1) on warning, (2) on probation, and (3) required to withdraw.

**D Grades.** While a grade of D is passing, it is not considered satisfactory performance. Any deficiency of grade points (below 2.00 over-all average) resulting from one or more D grades must be made up while enrolled in this College before the student is restored to good standing.

A student on warning or probation must repeat as soon as possible each course for which he earned a grade of D if the course is required by his program; in exceptional cases, this requirement may be waived by the student's program adviser (for freshmen, the Assistant Dean).

A student in good standing may choose to repeat a D provided he does so during the next two semesters that he is in residence. As a general principle, any student is well-advised to repeat a D immediately, if the course is an important prerequisite for other courses.

Credit is not transferable for courses in which D grades, or equivalent, were earned in another college.

**E Grades.** Neither credit nor grade points are allowed for a course in which a student earns the grade of E. Any deficiency of grade points (below 2.00 over-all average) resulting from one or more E grades must be made up while enrolled in this College before the student is restored to good standing.

A student earning a grade of E in a course required by his program must repeat it as soon as possible.

**Rules Governing Scholastic Standing.** The following chart defines the rules that govern scholastic standing:

| Scholastic Standing at Beginning of Semester | Student's Achievement Record for the Semester | | Resultant Standing |
|---|---|---|---|
| | Semester Average | Over-all Average | |
| In good standing | 1.70 to less than 2.00<br>1.10 to less than 1.70<br>less than 1.10 | | Placed on warning<br>Placed on probation<br>Required to withdraw† |
| On warning | 2.00 or more<br>2.00 or more*<br>1.70 to 2.00<br>less than 1.70 | less than 2.00 | Continued on warning<br>Continued on warning<br>Placed on probation<br>Required to withdraw† |
| On probation | 2.00 or more<br>2.00 or more*<br><br>less than 2.00 | less than 2.00 | Placed on warning<br>Continued on probation<br>Required to withdraw† |
| In good standing, but on probation twice previously | less than 1.70 | | Required to withdraw† |
| On warning or probation | 2.00 or more for full schedule | 2.00 or more | Restored to good standing |

*For a schedule of courses less than a minimum full schedule.
†See Conditions for Reinstatement below.

**On Warning or Probation.** A student on warning or probation may continue his enrollment but should consult immediately with his counselor or program adviser to review his status and goals, and arrange any necessary adjustments in his program, work load, or plans for the future. See under D and E Grades above on repeating courses.

In cases of extenuating circumstances, a student on warning or probation may be restored to good standing at the discretion of the faculty Committee on Scholastic Standing.

**Conditions for Reinstatement.** When a student is required to withdraw because of poor scholarship, his further enrollment is contingent upon reinstatement on probation by the faculty Committee on Scholastic Standing. He has the privilege of presenting the associated circumstances, and the reasons for his low record, to the Committee in a manner specified by the Committee, normally in an interview. On sufficient and convincing evidence of the extenuating circumstances, and of the student's ability and motivation to improve his performance, the Committee may reinstate him on probation and specify the credit-hour load and expected performance. Upon being reinstated, his achievement will be judged by the rules that cover "On Probation" (above).

A student reinstated after an absence of one semester or more must also re-establish his enrollment with the Assistant Dean's Office.

**Incompletes.** When a student is prevented by illness, or by any other cause beyond his control, from taking an examination or from completing any part of a course, or if credit in a course is temporarily withheld, the mark I with a qualifying grade may be given to indicate that the course has not been completed. An incomplete course is thus reported IA, IB, IC, ID, or IE. The grade indicates the quality of work done in the part of the course which has been completed.

The qualifying grade is used to compute temporary averages. If an incomplete is reported without a qualifying grade, it is considered temporarily as a D grade.

In order that credit may be allowed, the required work must be completed before the end of the eighth week of the first semester (not including summer session) that the student is enrolled after the semester in which the incomplete grade was recorded, unless an extension is granted by the Assistant Dean. When completed, the final grade will be based upon all of the work done in the course and may or may not be the grade reported for the partly completed course.

If the student does not meet the above stated requirements, the I grade will be changed to E by the Records Office and averages computed accordingly.

**Other Irregularities.** Irregularities associated with failure to submit change in classification to the Records Office are identified on the student's Academic Record by an appropriate designation such as NR (no report) or ED (unofficial drop). No credit will be allowed a student for work in any course unless the election of that course is entered officially on his classification record.

The student must consult the Assistant Dean's Office on the necessary procedures for resolving such cases, if there has been an error.

**Repeating Courses.** For D and E grades, see above. Except as provided for D grades, a student may not repeat a course which he has already passed. In exceptional cases, this rule may be waived by the student's program adviser (for freshmen, the Assistant Dean) after consultation with the department of instruction involved.

Any time a course is repeated in accordance with the rules, both grades will be used in computing the student's over-all averages, but the hours of credit are used only once in computing the total hours credit toward his degree.

**Grade Reports.** Unless withheld for infringement of rules, each semester's grades are reported to the student. When he is not in good scholastic standing, a status report is sent to both the student and the parent.

## CLASS STANDING

The number of credit hours achieved toward graduation at the close of the semester or summer session most recently enrolled, plus "incompletes," "no reports," and "unofficial drops," will be used to determine class standing for purposes of assessing fees and the necessary statistics. Appeals concerning class-level designations should be made at the Assistant Dean's Office.

| *Class* | *Credit Hours* |
|---|---|
| *Underclassmen* | |
| Freshman | 0 to 29 |
| Sophomore | 30 to 61 |
| *Upperclassmen* | |
| Junior | 62 to 99 |
| Senior | 100 or more |

A transfer student is classified in this manner in terms of the tentative adjustment of credit hours applicable to his elected program. When, in the opinion of his program adviser, there is a reasonable expectancy that a transfer student will graduate within one year, he will be classified as a senior.

Special students, guest students, and students on a prescribed program are considered upperclassmen for purpose of assessing fees.

## TRANSFERRING OUT, WITHDRAWAL, AND READMISSION

**Transferring Out.** A student who wishes to pursue his studies in another unit of the University must apply for admission to that unit and be accepted in order to continue his enrollment in the University. In general, a student's scholastic standing determines his eligibility for admission to other colleges.

The Assistant Dean may be consulted for procedures to effect a transfer.

**Withdrawal.** Withdrawal from the College for a justifiable reason at any time during a semester requires the approval of the Assistant Dean. A student under twenty-one may be required to present evidence of parent's approval.

After the eighth week of a semester, a student requesting withdrawal without record must present evidence of extraordinary circumstances.

When a student plans not to return the next semester, his attention is called to the regulations on enrollment deposit.

**Honorable Dismissal.** Honorable dismissal will be granted to a student who wishes to transfer to another college when his record is void of any College of Engineering or University action regarding misconduct.

**Readmission.** When a former student wishes to re-enroll, he must apply to the Assistant Dean for readmission and should do so at least two months before the date of desired enrollment.

A student who was required to withdraw must first be reinstated on probation by the Committee on Scholastic Standing.

## DIPLOMA AND COMMENCEMENT

To be recommended for a degree a student must file formal application for the diploma in the Records Office, 263 West Engineering Building. This should be done early in the semester in which the student is reasonably certain of completing his work for the degree. If he does not complete his work in that semester, it will be necessary for him to renew his application early in the succeeding semester.

All students who are entitled to receive diplomas are expected to be present at the Commencement exercises appropriate to the date of graduation.

## REGISTRATION AS PROFESSIONAL ENGINEER

Modern civilization has found it necessary to regulate the practice of persons whose activities deal with the protection of life, health, property, or other rights. A profession such as engineering is judged by the qualifications and competency of all who use its name. Therefore, to provide the public with a clearly recognizable line of demarcation between the engineer and nonengineer, the state establishes standards and provides the legal processes associated with the registration of individuals and their practice as professional engineers.

In Michigan, the State Board of Registration for Architects, Professional Engineers, and Land Surveyors provides an opportunity for senior engineers while on the campus to take the first examination to begin planning for registration. It is a general coverage of the fundamentals common to all fields of specialization, including mathematics. After a minimum of four years of experience, which may include one year of graduate study, the engineer-in-training will take an examination in his chosen field and one in a general area relating to business and professional practices and ethics.

On completing his registration, an engineer receives authority to practice his profession before the public and establishes his professional standing on the basis of legal requirements. While state laws may differ in some respects, an engineer registered under the laws of one state will find that reciprocal agreements between states generally make possible ready transfer of privileges to other states.

## REQUIREMENTS FOR GRADUATION

The scholastic requirements for graduation are expressed in terms of the quality and level of attainment reached by the student rather than in terms of a total number of credit hours.

In order to secure a degree in the College of Engineering, a student must meet the following requirements:

1. (*a*) He must demonstrate a basic level of attainment in the fundamental fields common to all degree programs, equivalent to the satisfactory completion of the courses as specified under Group A (next section), and (*b*) he must satisfactorily complete 95 hours of professional, advanced, and elective courses (or their equivalent) as specified in the program of his choice under Group B (next section).
2. His final grade-point average for all courses taken while enrolled in the College of Engineering, Ann Arbor campus, must be 2.00 or more.
3. A student who has earned 30 hours or more of credit in the College of Engineering, Ann Arbor campus, prior to the beginning of his last 30 hours required for graduation, may elect six hours of the last thirty hours at another recognized college. All other students must complete their last 30 hours of work enrolled in the College of Engineering, Ann Arbor campus.
4. To obtain two bachelor's degrees in the College of Engineering, a student must complete the requirements of both degree programs. He must complete, in addition to those credit hours which are used to satisfy the requirements of one of the degree programs, a minimum of fourteen credit hours in pertinent technical subjects which must be used in satisfying the requirements of the other degree program. The credit hours used to satisfy each of the two program requirements must satisfy the grade-point-average requirement of 2.00 or more.

# Undergraduate Degree Programs

Each of the fourteen undergraduate degree programs is composed of two groups of subjects that are identified under the program descriptions as Group A and Group B.

For information on credit for courses taken at other recognized colleges or universities, see Admission with Advanced Standing.

## GROUP A SUBJECTS

Group A includes foundation subjects in those fundamental areas of communication, mathematics, and basic sciences that are common to all programs. The courses in the following schedule must be elected and passed or equivalent proficiencies must be demonstrated (see Requirements for Graduation):

| *Subject* | *Hours* | *Subjects to be elected or equivalent proficiencies to be demonstrated* |
|---|---|---|
| English Composition and Speech | 6 | English 111, 112, and 121 |
| Mathematics | 16 | Math. 115, 116, 215, and 216 |
| | *or* | |
| | 12 | Math. 185, 186, and 285 |
| Engineering Graphics | 3 | Eng. Graphics 101 |
| Chemistry | 5 or 8 | See Chemistry, page 27 |
| Physics | 10 | Physics 145 and 146 |
| | *or* | |
| | 8 | Physics 153 and 154 |

NOTE:—The number of hours elected by a student enrolled in the Unified Science sequence is generally 8 for chemistry and 8 for physics.

Appropriate college credit may be allowed a student for subjects in which he has qualified through the Advanced Placement Program as covered under Admission as a Freshman. Another possibility for attaining advanced credit is through demonstration of equivalent proficiency in any of the Group A subjects; this is done by observation of the extent of preparation, abilities, high school standing, and results of any placement examinations taken by the student. Such savings in credit hours resulting from careful planning of the high school program may serve either to materially decrease the time required for completing the degree requirements or to provide opportunity for special college elections.

Generally, suitable Group A subjects, with the possible exception of Engineering Graphics, are offered in liberal arts colleges and community colleges; under conditions of equivalency and satisfactory performance, they are transferable to any engineering program.

## GROUP B SUBJECTS

Group B for each program is composed basically of those professional subjects, advanced subjects, and electives that will prepare the student for the particular field of engineering he selects. Included are courses in advanced mathematics and science, engineering sciences, engineering analysis and design, and elective studies in both technical and nontechnical areas as outlined below.

The requirements for each program, a total of 95 credit hours, are specified under the heading Professional and Advanced Subjects and Electives.

**Elective Studies.** Each program provides in Group B some freedom for the student to elect subjects that satisfy his particular interests and aptitudes. His counselor or program adviser is in a position to make helpful recommendations.

Subject to the limitations of his program and to the approval of his counselor or program adviser, a student may elect: courses within the field in which he is enrolled and courses for which he is qualified in other engineering departments; appropriate courses in other colleges or schools of the University (e.g., mathematics; the physical, biological, social, and management sciences; the humanities; fine arts; and languages); and advanced courses in air, military, or naval science.

This plan is designed to permit the greatest freedom of choice of subjects consistent with the acquistion of a sound background and a desirable breadth of education. It provides the student an opportunity to explore areas of cultural interest, and to plan for continued or advanced study in a selected field—either in engineering and physical sciences or in other areas such as business administration, patent law, or bioengineering.

**Nontechnical Electives.** The programs vary in their requirements of nontechnical electives and in some instances the subjects from which a student may make his choices are specified in the list of Group B requirements. For those programs in which the term "nontechnical electives" is used, the student may choose from the following:

1. English beyond the required courses
2. Courses in the College of Architecture and Design whose major emphasis is on the fine arts
3. Courses offered by any instructional department or unit of the University except the following:
   *a*) A department already represented by a required course in the student's degree program
   *b*) The departments of Air, Military, or Naval Science
   *c*) The College of Engineering (see (1) above)
   *d*) The School of Business Administration
   *e*) The College of Architecture and Design (see (2) above)

Anyone wishing to discuss suitable elections in the College of Literature, Science, and the Arts may consult the Junior-Senior Counseling office, 1223 Angell Hall.

## TIME REQUIREMENT

The time required to complete a degree program depends on the background, ability, and interests of the individual student. Eight semesters plus a summer session, or nine semesters, can be used for planning purposes. Students who are admitted with advanced preparation, or with demonstrated ability to achieve at high levels, may materially accelerate their progress.

Students interested in the pursuit of graduate work may, under some conditions, receive credit for graduate level work taken in their last semester as an undergraduate (refer to the *Announcement* of the Horace H. Rackham School of Graduate Studies).

## AERONAUTICAL AND ASTRONAUTICAL ENGINEERING

*Program Adviser*: Associate Professor Eisley, 1507 East Engineering

The design of modern aircraft, missiles, and space vehicles involves problems in many branches of engineering and the sciences. The program in aeronautical engineering, therefore, has been arranged to provide the student with a broad and fundamental background. It includes a study of subsonic and supersonic aerodynamics with applications to the design of wings and bodies. A sequence of courses in propulsion treats the theory and design of power plants, with special emphasis on the turboprop, turbojet, ramjet, and rocket motors. The stress analysis and design of elastic bodies is offered in a series of structures courses. Studies in the field of instrumentation include principles of measurement, data transmission, automatic control, and systems analysis.

In the senior year, the engineering sciences described above are brought together in a sequence of courses that present the mechanics of flight. The performance and design of all types of flight vehicles are treated from the dynamics point of view.

All theoretical work is co-ordinated with laboratory periods in which the student acquires a working familiarity with modern experimental equipment.

Electives are provided with which the student may emphasize aerodynamics, propulsion, structures, aeroelasticity, mechanics of flight, or instrumentation as applied to various flight vehicle systems.

## REQUIREMENTS

Candidates for the degree B.S.E.(Ae.E.)—Bachelor of Science in Engineering (Aeronautical Engineering)—are required to complete the following program:

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | HOURS |
|---|---|
| English, Groups II and III | 4 |
| Chem.-Met. Eng. 250, Principles of Engineering Materials | 3 |
| Eng. Graphics 104, Geometry of Engineering Drawing | 2 |
| Econ. 401, Modern Economic Society | 3 |
| Math. 450, Advanced Mathematics for Engineers | 4 |
| Eng. Mech. 208, Statics | 3 |
| Eng. Mech. 210, Mechanics of Material | 4 |
| Eng. Mech. 212, Laboratory in Mechanics of Material | 1 |
| Eng. Mech. 343, Dynamics | 3 |
| Mech. Eng. 335, Thermodynamics I | 3 |
| Elec. Eng. 316, Circuit Analysis and Electronics | 4 |
| Aero. Eng. 200, General Aeronautics and Astronautics | 2 |
| Aero. Eng. 314, Structural Mechanics I | 4 |
| Aero. Eng. 320, Aerodynamics I | 4 |
| Aero. Eng. 330, Propulsion I | 3 |
| Aero. Eng. 414, Structural Mechanics II | 4 |
| Aero. Eng. 420, Aerodynamics II | 4 |
| Aero. Eng. 430, Propulsion II | 4 |
| Aero. Eng. 441, Mechanics of Flight | 4 |
| Aero. Eng. 471, Automatic Control Systems | 4 |
| Aero. Eng. 481, Airplane Design | 4 |
| Electives in the Humanities and Social Sciences | 12 |
| Electives* | 12 |
| Total hours in Group B | 95 |

## REPRESENTATIVE SCHEDULE

| FIRST SEMESTER | HOURS | SECOND SEMESTER | HOURS |
|---|---|---|---|
| Math. 115 | 4 | Math. 116 | 4 |
| Chem. 104 | 4 | Chem. 105 or 106 | 4 |
| English 111 | 3 | Physics 145 | 5 |
| English 121 | 1 | English 112 | 2 |
| Eng. Graphics 101 | 3 | Eng. Graphics 104 | 2 |
| | 15 | | 17 |

*A maximum of 4 hours of advanced air, army, or naval science (300 and 400 series) may be used as electives in this group.

| THIRD SEMESTER | HOURS |
|---|---|
| Math. 215 | 4 |
| Physics 146 | 5 |
| Aero. Eng. 200 | 2 |
| Eng. Mech. 208 | 3 |
| Elective | 3 |
| | 17 |

| FOURTH SEMESTER | HOURS |
|---|---|
| Math. 216 | 4 |
| Chem.-Met. Eng. 250 | 3 |
| English, Group II | 2 |
| Eng. Mech. 210 | 4 |
| Eng. Mech. 212 | 1 |
| Mech. Eng. 335 | 3 |
| | 17 |

| SUMMER SESSION | |
|---|---|
| Elective | 3 |
| Elec. Eng. 316 | 4 |
| | 7 |

| FIFTH SEMESTER | |
|---|---|
| Math. 450 | 4 |
| Aero. Eng. 320 | 4 |
| Eng. Mech. 343 | 3 |
| Aero. Eng. 314 | 4 |
| Elective | 2 |
| | 17 |

| SIXTH SEMESTER | |
|---|---|
| Aero. Eng. 414 | 4 |
| Aero. Eng. 330 | 3 |
| Aero. Eng. 420 | 4 |
| Aero. Eng. 441 | 4 |
| Elective | 2 |
| | 17 |

| SEVENTH SEMESTER | |
|---|---|
| Aero. Eng. 430 | 4 |
| Electives | 8 |
| Econ. 401 | 3 |
| | 15 |

| EIGHTH SEMESTER | |
|---|---|
| Aero. Eng. 471 | 4 |
| Aero. Eng. 481 | 4 |
| Electives | 6 |
| English, Group III | 2 |
| | 16 |

## CHEMICAL ENGINEERING

*Program Adviser*: Professor Joseph J. Martin, 3217 East Engineering

"Chemical engineering is that portion of the field of engineering where materials are made to undergo a change of composition, energy content, or state of aggregation." So states a recent report on Dynamic Objectives for Chemical Engineering prepared by the American Institute of Chemical Engineers. The report also says, "The characteristic functions of chemical engineers are the examination, design, and operation of processes and equipment that accomplish changes in chemical composition." The chemical engineer is the designer of plants, the controller of reactions, the maker of chemicals, and the supervisor of developmental research. He brings to bear on his problems the principles of the physical sciences, economics, and human relations. In these tasks he must be a dynamic individual who keeps up with the latest developments that pertain in any way to his job responsibility.

The work of the chemical engineer encompasses many industries, from the manufacture of chemicals and the refining of petroleum to nuclear energy and space technology. Because of this breadth, there are many special fields in which chemical engineers may concentrate. The following areas of specialization may be undertaken by the student in a regular chemical engineering program by electing the suggested groups of courses:

**Biochemical.** The combination of biological and chemical reactions to produce antibiotics, frozen foods, fermented products, vaccines, and even algae in space vehicles. Chem.-Met. Eng. 484, 584; Chem. 222, 223, Chem.-Met. Eng. 580.

**Combustion.** The oxidation of fuels to produce power, drive space craft, supply heat, or cause other chemical reactions. Chem.-Met. Eng. 445, 449; Aero. Eng. 632; Mech. Eng. 493, 495.

**Electrochemistry.** The use of electricity in promoting chemical reactions or the use of reactions to yield electricity directly. Chem.-Met. Eng. 510; Chem. 466, Elec. Eng. 330.

**Electronic Materials.** The design, preparation, and properties of materials that find application in the electronics industry. Chem.-Met. Eng. 551; Elec. Eng. 419, 442; Math. 404; Physics 453, 463.

**Graduate Studies.** Preparation for a more intensive and penetrating study of the field of chemical engineering and of frontier problems of research. Chem.-Met. Eng. 400, 430, 445; Math. 450, and language preparation.

**Instrumentation.** The measurement and control of variables in physical and chemical processes encountered in industry or space-age research. Chem.-Met. Eng. 446; Math. 404, 448; Instr. Eng. 510, 570.

**Machine Computation.** The application of electronic computers to the solution of engineering problems. Chem.-Met. Eng. 501; Math. 404, 473, 474; Instr. Eng. 510.

**Materials.** A knowledge of the preparation, structure, and behavior of materials that are used in production or pilot plant work. Chem.-Met. Eng. 450, 451, 472, 479, 560; Eng. Mech. 413, 416.

**Molecular.** Concentration on the properties of molecules as they determine the macroscopic behavior of liquid or solid matter such as plastics or transistors. Chem.-Met. Eng. 451, 560; Chem. 222, 223, 481, 482; Physics 425, 453.

**Nuclear.** A field closely allied to chemistry where nuclear reactions such as fission or spontaneous atomic disintegration occur. Nuc. Eng. 470, 550, 560.

**Polymers.** The field of large, long-chain molecules where new elastomers, synthetic fibers, or lubricants are designed or used. Chem.-Met. Eng. 451, 583; Chem. 222, 223, 538; Physics 418.

**Petroleum.** The production, transportation, refining, and chemical processing of oil and natural gas from the ground. Chem.-Met. Eng. 521, 522; Geol. 218.

**Propulsion and Rocketry.** The use of chemical, physical, and nuclear reactions to send machines through air, water, outer space, or across land. Chem.-Met. Eng. 449; Aero. Eng. 330, 430, 535, 632.

**Systems.** The methods of combining individual operations into a working whole with a maximum of efficiency and optimization. Chem.-Met. Eng. 481, 581; Instr. Eng. 570; Math. 448; Ind. Eng. 472.

Only the level of attainment in the various areas of the academic program is specified, with the route to that level depending upon the preparation and ability of the individual student. Because of this and because of the large proportion of elective courses, a student may readily enter the chemical engineering program from an engineering science program or from a science curriculum taken outside the College of Engineering.

## REQUIREMENTS

Candidates for the degree B.S.E.(Ch.E.)—Bachelor of Science in Engineering (Chemical Engineering)—are required to complete the program listed below. Since elective courses are nearly half the program, the student will be encouraged to plan the program which is best suited to his individual objectives with the advice and approval of the program adviser.

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)
(A typical sequence is shown in the first half of the representative schedule shown below.)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| **Basic Science** | HOURS |
|---|---|
| Advanced chemistry to include Chem. 221, 265, 266, and 346, or Chem. 195, 221, 468, and 469, or equivalent | 17 |
| An electronic computer course such as Math. 273 | 1 |
| **Chemical and Metallurgical Engineering Science** | |
| Introduction to Engineering Calculations, Chem.-Met. Eng. 200 | 3 |
| Thermodynamics I, Chem.-Met. Eng. 230 | 5 |
| Rate Processes I, Chem.-Met. Eng. 341 | 3 |
| Rate Processes II, Chem.-Met. Eng. 342 | 4 |
| Separations Processes I, Chem.-Met. Eng. 343 | 4 |
| Structure of Solids, Chem.-Met. Eng. 350 | 3 |
| **Electives** | |
| 1. Electives in humanities, social sciences, philosophy, languages, history of art, etc., including at least 4 credit hours of literature (See under English, and the *Announcement* of the College of Literature, Science, and the Arts for courses in these fields.) | 14 |
| 2. Electives in law, economics, and business administration (Typical economics electives are: Econ. 103, 104, 271, 272, 401, 411, 412, 421, 431, and 475; and business administration electives are: Bus. Ad. 305 and 306, Accounting 271 and 272, Finance 300 and 301, Ind. Relations 300, Marketing 300, and Statistics 300.) | 6 |

3. Electives in engineering science and analysis, such as mechanics of solids and fluids, network analysis, electronics, systems, energy conversion, electromagnetics, and thermodynamics ........................ 14
   (Typical electives are: Eng. Mech. 218, 219, 310, 324, 326, 343, 345, 400, 412, 422, 512, and 527; Elec. Eng. 210, 215, 220, 310, 315, 316, 320, 337, 418, 419, 422, and 425; Mech.-Eng. 335, 336, 471, 421, and 625; Chem.-Met. Eng., 430, 450, 470, 472, and 560; Instr. Eng. 510, 530, and 570; Nuc. Eng. 400 and 470; Civ. Eng. 580.)
4. Electives in advanced science and mathematics ..................... 10
   (Typical electives are: Math. 403, 404, 447, 450, and 552; Chem. 222, 223 in place of 221; Chem. 425, 447, 481, and 482; Physics 305, 347, 406, 411, 418, 453, 455, 456, 457, and 463; Zool. 101, 105.)
5. Electives in professional chemical engineering, to include laboratory, design, and materials (Minimum laboratory requirement is 2 hours) 11
   (Typical electives are: Chem.-Met. Eng. 390, 400, 430, 445, 446, 449, 450, 451, 460, 479, 480, 481, 484, and 500-level courses where appropriate.)

Total hours in Group B .................................... 95

A representative schedule is given below which shows one way in which the many elective alternatives may be chosen.

REPRESENTATIVE SCHEDULE

The number in parentheses preceding course name designates typical electives from the group under Electives above.

| FIRST SEMESTER | HOURS | SECOND SEMESTER | HOURS |
|---|---|---|---|
| English 111 | 3 | English 112 | 2 |
| Eng. Graphics 101 | 3 | Physics 145 | 5 |
| Chem. 107 | 5 | Math. 116 | 4 |
| Math. 115 | 4 | (4) Chem. 222 | 5 |
| | 15 | | 16 |

| THIRD SEMESTER | | FOURTH SEMESTER | |
|---|---|---|---|
| Math. 273 | 1 | Math. 216 | 4 |
| Physics 146 | 5 | Chem. 265 | 4 |
| Math. 215 | 4 | Chem.-Met. Eng. 230 | 5 |
| (4) Chem. 223 | 5 | English 121 | 1 |
| Chem.-Met. Eng. 200 | 3 | (3) Eng. Mech. 310 | 4 |
| | 18 | | 18 |

| FIFTH SEMESTER | | SIXTH SEMESTER | |
|---|---|---|---|
| Chem.-Met. Eng. 341 | 3 | Chem.-Met. Eng. 342 | 4 |
| Chem. 346 | 4 | Chem.-Met. Eng. 350 | 3 |
| Chem. 266 | 4 | (3) Eng. Mech. 343 | 3 |
| (3) Elec. Eng. 316 | 4 | (2) Acctg. 271 | 3 |
| (1) English, Group II | 2 | (4) Math. 404 | 3 |
| | 17 | (1) English, Group III | 2 |
| | | | 18 |

| SEVENTH SEMESTER | HOURS |
|---|---|
| Chem.-Met. Eng. 343 | 4 |
| (5) Chem.-Met. Eng. 479 | 3 |
| (2) Econ. 401 | 3 |
| (1) Russian | 4 |
| (3) Eng. Mech. 422 | 3 |
| | — |
| | 17 |

| EIGHTH SEMESTER | HOURS |
|---|---|
| (5) Chem.-Met. Eng. 460 | 3 |
| (5) Chem.-Met. Eng. 480 | 3 |
| (5) Chem.-Met. Eng. 481 | 3 |
| (4) Adv. Math. | 2 |
| (1) Russian | 4 |
| (1) Humanities | 2 |
| | — |
| | 17 |

## BIOCHEMICAL ENGINEERING

*Adviser*: Professor L. L. Kempe

Understanding of biological as well as physical sciences offers challenging opportunities to biochemical engineers in guiding the commercial development of products and processes required for human existence.

Current efforts in this exciting and progressive phase of chemical engineering involve work with antibiotics, freeze-dried foods, vaccines, marine plywood, tooth-hardening chemicals, DDT, potable water from the sea, detergents, algae in space vehicles, prosthetic metals, food yeast from industrial wastes, and frozen concentrated orange juice.

Electives adapted for the program in biochemical engineering: Group 3, Chem.-Met. Eng. 580; Group 4, Chem. 222 and 223, Zool. 101 and 105; Group 5, Chem.-Met. Eng. 484 and 485.

## COMBINED PROGRAMS

### CHEMICAL ENGINEERING AND METALLURGICAL ENGINEERING

Degrees in both chemical and metallurgical engineering may be earned by taking fourteen additional hours. Students in the chemical engineering program who desire to earn a degree in metallurgy as well will take fourteen hours in courses in metallurgical engineering in the field of process, physical, and mechanical metallurgy. Students in the metallurgical program will take six additional hours of chemistry and eight hours of professional chemical engineering courses, to include laboratory and engineering synthesis for a total of fourteen additional hours. These programs must be formulated in consultation with both program advisers.

### CHEMICAL ENGINEERING AND CHEMISTRY

*Advisers:* Associate Professor Robert C. Taylor, College of Literature, Science, and the Arts; Professor Bigelow, College of Engineering

Combined degrees, B.S.Chem. and B.S.E. (Ch.E.), are offered—chemistry in the College of Literature, Science, and the Arts and chemical engineering in the College of Engineering.

This program aims to supply the demands of students and of industry for a strong curriculum in chemistry and chemical engineering. It is also excellent preparation for further graduate study and for research or development.

During the first four semesters the student is under the complete jurisdiction of the College of Literature, Science, and the Arts. After completing the work of the first four semesters the student is under the complete jurisdiction of the College of Engineering. After satisfactorily completing all the course requirements listed below, the student will be granted the two degrees, B.S.Chem. and B.S.E. (Ch.E.).

Candidates for the degrees of Bachelor of Science in Chemistry in the College of Literature, Science, and the Arts, and of Bachelor of Science in Engineering (Chemical Engineering) in the College of Engineering are required to complete the following program:

| | HOURS | HOURS |
|---|---|---|
| HUMANITIES GROUP | | 26 |
| English 123, 124 (L. S. & A.) and Groups II and III (Engineering) | 10 | |
| German 101, 102, 231, 232 | 16 | |
| MATHEMATICS AND SCIENCE GROUP | | 69 to 74 |
| Chem. 104, 106 or 191, 222, 223, 346, 421, 447, 468, 469, 481, 482, and elective 3 hours | 43 or 44 | |
| Math. 115, 116, 215, 216 (or 185, 186, 285), 273, and 403 or 404 | 16 to 20 | |
| Physics 145, 146 | 10 | |
| SOCIAL SCIENCES GROUP | | 9 |
| Econ. 103, 104 | 6 | |
| Acctg. 271 | 3 | |
| ENGINEERING COURSES | | 45 |
| Electives in engineering science and analysis (see requirements for B.S.E. (Ch.E.) | 14 | |
| Chem.-Met. Eng. 200, 230, 341, 342, 343 | 19 | |
| Professional electives in Chem.-Met. Eng. | 12 | |
| ELECTIVES IN HUMANITIES | | 6 |
| Total | 155 to | 160 |

## CIVIL ENGINEERING

*Program Adviser:* Associate Professor Harris, 313 West Engineering

Civil Engineering, originally named to distinguish it from military engineering, has always covered a wide field of engineering practice. Civil engineers plan, design, and supervise the construction of roads, railroads, harbors, buildings, tunnels, waterways, bridges, dams, airfields, canals, water supply and sewerage systems, and the many other facilities necessary for public works and industrial development. They plan the conservation, utilization, and control of water resources. They operate in the field of surveying and mapping. The nature of the civil engineer's work requires that he not only have a broad basic foundation in the physical sciences, but also that he be alert to the economic and social significance of what he plans and builds. This aspect of his educational foundation has been a strong contributing factor in qualifying him for positions of leadership in both industry and government. In the junior and senior years the curriculum provides an opportunity for elective courses in one of the following areas which exemplify the more important fields of civil engineering:

**Construction.** The methods and techniques of modern construction; fundamental principles of construction applicable to all types of engineering structures; business and legal principles of contracting as applied in the field of construction.

**Geodetic Engineering.** Theory and practical application of surveying and surveying techniques; theoretical and applied geodesy, figure of the earth, local and extended control surveys; precise measurements and the adjustment of observations; design and execution of municipal surveys, topographic mapping projects, boundary surveys and land subdivision; industrial applications of surveying techniques; research in fields of instrumentation, computation, mapping and photogrammetry, and the problems of land surveying and route location.

**Highway.** Location, design, construction, and maintenance of various types of roads and streets, including materials, surveys, plans, specifications, economics, financing, and administration.

**Hydraulic.** The application of the fundamental principles of hydraulics and hydrology to the development of water power, flood control, drainage, and improvement of rivers and harbors, and other hydraulic structures. Laboratory facilities and instruction are offered for students who wish to engage in research work in hydrology and hydraulics that will lead to advanced degrees.

**Railroad.** The design, construction, and operation of railroad properties, including metropolitan terminals, statistical analysis of operating data, freight and passenger traffic, economics, financing, administration and regulation.

**Sanitary.** The planning, construction, and operation of water works, sewerage and drainage systems, water-purification plants, and works for the treatment and disposal of city sewage and industrial wastes; improvement and regulation of natural waters for purposes of municipal and industrial use.

**Soil Mechanics.** The evaluation of soil properties and environmental conditions in foundations of earth-supported structures; mass stability in excavations and subsurface construction. Soil engineering: use of soil characteristics and properties and soil classification in design and construction of highways, railways, airports, and other surface facilities.

**Structural.** The theory, design, and construction of structures, such as bridges, buildings, dams, retaining walls, and reservoirs, involving the use of steel, reinforced concrete, and lumber; the testing and utilization of soils in foundations and subsurface construction.

**Transportation.** Methods of increasing the efficiency and safety of traffic movement; street and off-street parking; traffic surveys, geometrical design of urban and rural highways, traffic control devices, and other means of regulating and controlling the use of highways.

## REQUIREMENTS

Candidates for the degree B.S.E.(C.E.)—Bachelor of Science in Engineering (Civil Engineering)—are required to complete the following:

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | HOURS |
|---|---|
| Civ. Eng. 260, 261, 362, Surveying | 10 |
| English, Groups II and III | 4 |
| Eng. Graphics 102, Descriptive Geometry | 3 |
| Eng. Mech. 208, Statics | 3 |
| Eng. Mech. 210, Mechanics of Material | 4 |
| Eng. Mech. 212, Laboratory in Mechanics of Material | 1 |
| Eng. Mech. 324, Fluid Mechanics | 3 |
| Eng. Mech. 343, Dynamics | 3 |
| Advanced Mathematics | 3 |
| Elec. Eng. 316, Circuit Analysis and Electronics | 4 |
| Mech. Eng. 333, Thermodynamics and Heat Transfer | 4 |
| Civ. Eng. 312, Theory of Structures | 3 |
| Civ. Eng. 313, Elementary Design of Structures | 3 |
| Civ. Eng. 350, Concrete Mixtures | 1 |
| Civ. Eng. 370, Transportation Engineering | 3 |
| Civ. Eng. 400, Specifications and Contracts | 2 |
| Civ. Eng. 415, Reinforced Concrete | 3 |
| Civ. Eng. 420, Hydrology | 3 |
| Civ. Eng. 421, Hydraulics | 2 |
| Civ. Eng. 445, Engineering Properties of Soil | 3 |
| Civ. Eng. 480, Water Supply and Treatment | 3 |
| Civ. Eng. 481, Sewerage and Sewage Treatment | 2 |
| Geol. 218 | 4 |
| Econ. 401 | 3 |
| Humanities and social sciences (see below) | 8 |
| Technical option group* (see below) | 10 |
| Total hours in Group B | 95 |

* A maximum of six hours of advanced air, army, or naval science (300 and 400 series) may be used as electives in this group.

The electives in humanities and social sciences are to be approved courses in such fields as economics, history of art, history, law, literature, philosophy, political science, psychology, and sociology.

The technical option group will be composed of an approved sequence of subjects in some area of civil engineering practice and appropriate electives. As early as possible a student should select his particular area of interest and confer with the adviser in that field regarding the electives required for the completion of his program. Groupings of subjects which meet the technical group requirements are available in the following areas:

1. Construction Engineering—Adviser: Associate Professor Harris
2. Geodetic Engineering—Adviser: Professor Berry
3. Highway Engineering—Adviser: Associate Professor Cortright
4. Hydraulic Engineering—Adviser: Professor Brater
5. Railroad Engineering—Adviser: Associate Professor Heimbach
6. Sanitary Engineering—Adviser: Professor Borchardt
7. Soil Mechanics—Adviser: Professor Housel
8. Structural Engineering—Adviser: Professor Maugh
9. Transportation Engineering—Adviser: Professor Kohl

Other combinations of technical courses for special fields of professional interest can be formulated and approved by the program adviser to meet the needs of individual students.

REPRESENTATIVE SCHEDULE

| FIRST SEMESTER | HOURS |
|---|---|
| Math. 115 | 4 |
| Chem. 104 | 4 |
| Eng. Graphics 101 | 3 |
| English 111 | 3 |
| English 121 | 1 |
| | — |
| | 15 |

| SECOND SEMESTER | HOURS |
|---|---|
| Math. 116 | 4 |
| Physics 145 | 5 |
| English 112 | 2 |
| Chem. 106 | 4 |
| | — |
| | 15 |

| THIRD SEMESTER | |
|---|---|
| Math. 215 | 4 |
| Eng. Graphics 102 | 3 |
| English, Group II | 2 |
| Eng. Mech. 208 | 3 |
| Civ. Eng. 260 | 3 |
| Civ. Eng. 350 | 1 |
| | — |
| | 16 |

| FOURTH SEMESTER | |
|---|---|
| Math. 216 | 4 |
| Physics 146 | 5 |
| Eng. Mech. 210 | 4 |
| Eng. Mech. 212 | 1 |
| Civ. Eng. 261 | 3 |
| | — |
| | 17 |

| SUMMER SESSION (at Camp Davis) | |
|---|---|
| Civ. Eng. 362 | 4 |
| Geol. 218 | 4 |
| | — |
| | 8 |

| FIFTH SEMESTER | HOURS |
|---|---|
| Eng. Mech. 324 | 3 |
| Civ. Eng. 312 | 3 |
| Civ. Eng. 370 | 3 |
| Civ. Eng. 420 | 3 |
| Advanced mathematics | 3 |
| Elective* | 2 |
| | 17 |

| SIXTH SEMESTER | HOURS |
|---|---|
| Eng. Mech. 343 | 3 |
| Civ. Eng. 415 | 3 |
| Civ. Eng. 421 | 2 |
| Civ. Eng. 445 | 3 |
| Civ. Eng. 480 | 3 |
| Elective* | 3 |
| | 17 |

| SEVENTH SEMESTER | |
|---|---|
| Civ. Eng. 313 | 3 |
| Civ. Eng. 400 | 2 |
| Elec. Eng. 316 | 4 |
| Civ. Eng. 481 | 2 |
| English, Group III | 2 |
| Technical elective | 3 |
| | 16 |

| EIGHTH SEMESTER | |
|---|---|
| Mech. Eng. 333 | 4 |
| Econ. 401 | 3 |
| Technical electives | 7 |
| Elective* | 3 |
| | 17 |

## COMBINED PROGRAM WITH COLLEGE OF LITERATURE, SCIENCE, AND THE ARTS

*Advisers:* Associate Professor John A. Dorr, College of Literature, Science, and the Arts; Associate Professor Harris, College of Engineering

As one of the combined programs referred to on page 19, the College of Engineering and the College of Literature, Science, and the Arts offer a combined program which leads to the degrees Bachelor of Science in Engineering (Civil Engineering) and Bachelor of Arts—B.S.E. (C.E.) and A.B.

This program is designed to meet the desires of those who wish to have a broader background in the humanities and liberal arts than can be offered in the regular four-year civil engineering curriculum. Many civil engineers find a need for a humanistic and liberal arts background in their professional work, particularly as they relate their designs and constructions to the economic and social demands of society.

The program includes those courses in languages, literature, fine arts, philosophy, and history which would normally be taken by a student receiving a Bachelor of Arts degree with science as his major. At the same time, his science elections are planned in such a manner as to satisfy the requirements for both degrees. Upon completion of the five-year program, the student will have fulfilled all of the requirements for the Bachelor of Science in Engineering (Civil Engineering) degree and for the Bachelor of Arts degree. The degrees will be granted on completion of the prescribed program, with the understanding that if military science is elected it must be carried in addition to the full requirements of the regular curriculum.

A student electing the five-year combined program will enroll in the College of Literature, Science, and the Arts for the first four semesters. He will then enroll in the College of Engineering for the remaining six

*Electives in the humanities and social sciences group.

semesters and summer session. The complete program is as follows:

| | HOURS | HOURS |
|---|---|---|
| HUMANITIES GROUP | | 37 |
| English 123, 124, 269 | 9 | |
| History of Art 101 or 102 | 4 | |
| Foreign language or social sciences* | 16 | |
| Speech 211 | 2 | |
| Philos. 131 or 134, 133 | 6 | |
| MATHEMATICS AND SCIENCE GROUP | | 37 (to 42) |
| Math. 115, 116, 215, 216 or 185, 186, 285 | 16 (or 12) | |
| Advanced mathematics | 3 | |
| Chem. 104, 106, or 107 and Psych. 101 | 8 (or 9) | |
| Geol. 218 (at Camp Davis) | 4 | |
| Physics 145, 146 | 10 | |
| SOCIAL SCIENCES GROUP | | 14 |
| Acctg. 271 | 3 | |
| Econ. 103, 104 | 6 | |
| Electives in College of L., S., & A. | 5 | |
| ENGINEERING GROUP | | 79 |
| Eng. Graphics 101, 102 | 6 | |
| Chem.-Met. Eng. 250 | 3 | |
| Eng. Mech. 208, 210, 212, 324, 343 | 14 | |
| Elec. Eng. 316 | 4 | |
| Mech. Eng. 252, 333 | 6 | |
| Civ. Eng. 260, 261, 312, 313, 350, 362 (at Camp Davis), 370, 400, 415, 420, 421, 445, 480, 481, group options | 46 | |
| Total | 167 to | 172 |

## ELECTRICAL ENGINEERING

*Program Adviser:* Professor Holland, 2511 East Engineering

The electrical engineer is concerned with electrical energy and its applications. In our homes we have electric refrigerators, electrically controlled heating and air-conditioning units, phonographs, radios, and television sets. In our communities are electric power plants and power distribution lines, electrical transportation, and communication systems. The modern automobile, and still more the modern aircraft, carries a bewildering array of electric controls, gages, and instruments without which our present automobile and aircraft transportation would be impossible. Radar, lasers, masers, guided missiles, space vehicles, and scores of other such developments are all in the field of electrical engineering.

The program in electrical engineering emphasizes basic theory and provides the student with a broad and fundamental background. A student may achieve by careful selection of elective courses, however, a measure

*The College of Literature, Science, and the Arts requires that during his fourth semester the student demonstrate, by examination, proficiency in a foreign language. If a student satisfies this requirement prior to the completion of 16 hours of language course work, he will take the remaining hours in foreign language, literature, or the social sciences.

of specialization even within the basic undergraduate program. Extensive specialization should be reserved for graduate study.

The facilities of the Electrical Engineering Department include the following research laboratories: Adaptive and Control Systems, Communication Sciences, Cooley Electronics, Digital Computer Engineering, Electromagnetic Materials, Electron Physics, Information Systems, Plasma Engineering, Power Systems, Radiation, Radio Astronomy, and Space Physics Research.

## REQUIREMENTS

Candidates for the degree B.S.E.(E.E.)—Bachelor of Science in Engineering (Electrical Engineering)—are required to complete the following program:

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | HOURS |
|---|---|
| Eng. Graphics 104, Geometry of Engineering Drawing | 2 |
| Chem.-Met. Eng. 250, Principles of Engineering Materials | 3 |
| Math. 273, Elementary Computer Techniques | 1 |
| Math. 450, Advanced Mathematics for Engineers *or* Math. 404, Differential Equations | 4 or 3 |
| English, Groups II and III | 4 |
| Econ. 103, 104,* Principles of Economics | 6 |
| Eng. Mech. 310, Statics and Stresses | 4 |
| Eng. Mech. 324, Fluid Mechanics | 3 |
| Eng. Mech. 343, Dynamics | 3 |
| Mech. Eng. 252, Engineering Materials and Manufacturing Processes | 2 |
| Mech. Eng. 331, Classical and Statistical Thermodynamics | 4 |
| Mech. Eng. 343, Machine Design | 3 |
| Elec. Eng. 210, Circuits I | 4 |
| Elec. Eng. 220, Electromagnetic Field Theory I | 3 |
| Elec. Eng. 301, Introduction to Systems Engineering | 2 |
| Elec. Eng. 310, Circuits II | 4 |
| Elec. Eng. 330, Electronics and Communications I | 4 |
| Elec. Eng. 343, Energy Conversion and Control I | 3 |
| Elec. Eng. 360, Electrical Measurements | 3 |
| Elec. Eng. 380, Physical Electronics of Electron Devices I | 4 |
| Elec. Eng. 410, Circuits III | 3 |
| Elec. Eng. 420, Electromagnetic Field Theory II | 3 |
| Elec. Eng. 444, Energy Conversion and Control II | 4 |
| Elec. Eng. 470, Electrical Design | 4 |
| Nontechnical electives | 6 |
| Electives† | 9 or 10 |
| Total hours in Group B | 95 |

*Econ. 401 and Acctg. 271, or Econ. 401 and three additional hours of nontechnical electives also will satisfy this requirement.

†A maximum of four hours of advanced air, army, or naval science (300 and 400 series) may be used as electives in this group.

REPRESENTATIVE SCHEDULE

For studies of the first year, see page 24

| THIRD SEMESTER | HOURS | FOURTH SEMESTER | HOURS |
|---|---|---|---|
| Math. 215 | 4 | Math. 216 | 4 |
| Math. 273 | 1 | Elec. Eng. 220 | 3 |
| Physics 146 | 5 | Chem.-Met. Eng. 250 | 3 |
| Elec. Eng. 210 | 4 | English, Group II | 2 |
| Nontechnical elective | 3 | Eng. Graphics 104 | 2 |
| | — | Nontechnical elective | 3 |
| | 17 | | — |
| | | | 17 |

| SUMMER SESSION | HOURS |
|---|---|
| Elec. Eng. 310 | 4 |
| Mech. Eng. 331 | 4 |
| | — |
| | 8 |

| FIFTH SEMESTER | HOURS | SIXTH SEMESTER | HOURS |
|---|---|---|---|
| Elec. Eng. 360 | 3 | Elec. Eng. 301 | 2 |
| Elec. Eng. 380 | 4 | Elec. Eng. 330 | 4 |
| Eng. Mech. 310 | 4 | Elec. Eng. 343 | 3 |
| Math. 450 *or* Math. 404 | 4 or 3 | Eng. Mech. 343 | 3 |
| Econ. 103* | 3 | Mech. Eng. 252 | 2 |
| | — | Econ. 104* | 3 |
| | 18 or 17 | | — |
| | | | 17 |

| SEVENTH SEMESTER | HOURS | EIGHTH SEMESTER | HOURS |
|---|---|---|---|
| Elec. Eng. 410 | 3 | Elec. Eng. 420 | 3 |
| Elec. Eng. 444 | 4 | Elec. Eng. 470 | 4 |
| Eng. Mech. 324 | 3 | English, Group III | 2 |
| Electives | 6 or 5 | Mech. Eng. 343 | 3 |
| | — | Electives | 4 |
| | 16 or 15 | | — |
| | | | 16 |

## ENGINEERING MECHANICS

*Program Adviser:* Professor Clark, 201 West Engineering

Rapid technological developments have brought about an increasing need for engineers who are exceptionally well-trained in the basic sciences. The need is acute throughout industry and government as well as in research institutions and in universities; to help fill this need is the purpose of the program in engineering mechanics. Men with training in the field of engineering mechanics are sought by organizations of all kinds, particularly by those working on modern developments. Most young men in the field

*Econ. 401 and Acctg. 271, or Econ. 401 and three additional hours of nontechnical electives also will satisfy this requirement.

are engaged in highly technical work, but many, like other engineers, enter supervision and management.

A student majoring in engineering mechanics gets the same first year program as most other students. He may, in fact, choose this specialty up to the beginning of the junior year without loss of time. The later years are filled mainly with more advanced mechanics and science courses which are designed to acquaint the student with the fundamental principles on which engineering science is based. The required mathematics exceeds that in most curriculums, but the engineering emphasis is always present.

The major areas of study in the bachelor's program are strength of materials, elasticity, plasticity, dynamics, vibrations, fluid mechanics, and thermodynamics. The department has modern laboratories, and computer and research facilities. The association of theory with the physical aspects of the work is very close. To gain practice in applying the fundamental principles of engineering, the program contains a group option in some other technical area chosen by the student. In addition, there are seven to nine hours of free electives.

Graduate work toward a master's degree is a natural sequence for many mechanics graduates who qualify. It is also open to graduates in other areas of engineering.

## REQUIREMENTS

Candidates for the degree B.S.E. (E.M.)—Bachelor of Science in Engineering (Engineering Mechanics)—are required to complete the following program:

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | HOURS |
|---|---|
| English, Group II and III | 4 |
| Math. 404, Differential Equations | 3 |
| Math. 447, Modern Operational Mathematics, or an approved alternate | 2 |
| Math. 450, Advanced Mathematics for Engineers | 4 |
| Civ. Eng. 312, Theory of Structures | 3 |
| Elec. Eng. 316, Circuit Analysis and Electronics | 4 |
| Mech. Eng. 335, Thermodynamics | 3 |
| Chem.-Met. Eng. 250, Principles of Engineering Materials | 3 |
| Eng. Graphics 102, Descriptive Geometry | 3 |
| Eng. Mech. 208, Statics, or Eng. Mech. 218 | 3 |
| Eng. Mech. 210, Mechanics of Material, or Eng. Mech. 219 | 4 |
| Eng. Mech. 212, Laboratory in Mechanics of Material, *or* Eng. Mech. 402 | 1 or 2 |
| Eng. Mech. 324, Fluid Mechanics, *or* Eng. Mech. 326 | 3 or 4 |
| Eng. Mech. 343, Dynamics, *or* Eng. Mech. 345 | 3 |
| Eng. Mech. 403, Experimental Mechanics | 2 |
| Eng. Mech. 412, Intermediate Mechanics of Material | 3 |

| | HOURS |
|---|---|
| Eng. Mech. 422, Intermediate Mechanics of Fluids | 3 |
| Eng. Mech. 441, Intermediate Mechanics of Vibrations | 3 |
| Eng. Mech., approved advanced courses | 7 |
| Econ. 401 | 3 |
| Nontechnical electives | 9 |
| Group options and electives* (see below) | 22 |
| Total hours in Group B | 95 |

Every student is required to elect a complete group option of 12 to 14 hours from some other program in the College of Engineering in order that his theoretical training may be correlated with engineering practice in that field. Electives, 8 to 10 hours, selected in conference with the adviser, will complete this group of requirements.

Suggested group options are:

Aerodynamics
Aeromechanics
Chemical Engineering
Dynamics
Electrical Engineering
Hydraulics
Instrumentation
Machine Design
Metallurgy
Meteorology and Oceanography
Naval Architecture
Nuclear Engineering
Physics
Propulsion
Structural Engineering
Others arranged

Details of these can be obtained from the program adviser, and options in other areas can be arranged in conference with him.

## REPRESENTATIVE SCHEDULE

The courses making up the group option are denoted by an asterisk; in this case, the suggested Electrical Engineering option is used as an example.

| FIRST SEMESTER | HOURS |
|---|---|
| Math. 115 | 4 |
| Chem. 103, 104, or 107 | 4 or 5 |
| Eng. Graphics 101 | 3 |
| English 111 | 3 |
| English 121 | 1 |
| | 15 or 16 |

| SECOND SEMESTER | HOURS |
|---|---|
| Math. 116 | 4 |
| Physics 145 | 5 |
| Chem. 105 or Eng. Graphics 102 | 4 or 3 |
| English 112 | 2 |
| Nontechnical elective | 2 |
| | 17 or 16 |

| THIRD SEMESTER | |
|---|---|
| Math. 215 | 4 |
| Physics 146 | 5 |
| Eng. Mech. 208 or 218 | 3 |
| English, Group II | 2 |
| Nontechnical elective | 2 |
| | 16 |

| FOURTH SEMESTER | |
|---|---|
| Math. 216 | 4 |
| Chem.-Met. Eng. 250 | 3 |
| Eng. Mech. 210 | 4 |
| Mech. Eng. 335 | 3 |
| Eng. Mech. 343 | 3 |
| | 17 |

*A maximum of six hours of advanced air, army, or naval science (300 and 400 series) may be used as electives in this group.

| SUMMER SESSION | HOURS |
|---|---|
| Math. 404 | 3 |
| Eng. Mech. 324 | 3 |
| | 6 |

| FIFTH SEMESTER | HOURS |
|---|---|
| Math. 450 | 4 |
| Elec. Eng. 210 or 316 | 4 |
| Elec. Eng. 220* | 3 |
| Eng. Mech. 412 | 3 |
| Nontechnical elective | 2 |
| | 16 |

| SIXTH SEMESTER | HOURS |
|---|---|
| English, Group III | 2 |
| Elec. Eng. 310* | 4 |
| Eng. Mech. 403 | 2 |
| Eng. Mech. 441 | 3 |
| Eng. Mech. 422 | 3 |
| Elective | 3 |
| | 17 |

| SEVENTH SEMESTER | HOURS |
|---|---|
| Elec. Eng. 438* | 4 |
| Math. 448 | 4 |
| Civ. Eng. 312 | 3 |
| Eng. Mech. 402 | 2 |
| Eng. Mech. 545 | 3 |
| | 16 |

| EIGHTH SEMESTER | HOURS |
|---|---|
| Elec. Eng. 445* or 430* | 4 |
| Econ. 401 | 3 |
| Eng. Mech. 522 | 3 |
| Nontechnical elective | 3 |
| Elective | 2 |
| | 15 |

## INDUSTRIAL ENGINEERING

*Program Adviser:* Professor Gage, 235 West Engineering

Industrial engineering is concerned with the design, improvement, and installation of integrated systems of men, materials, and equipment; drawing upon specialized knowledge and skill in the mathematical, physical, and social sciences, together with the principles and methods of engineering analysis and design; to specify, predict, and evaluate the results to be obtained from such systems. The industrial engineer is primarily interested in problems which involve economy in the use of money, materials, time, human effort, and energy. The industrial engineer should combine the basic aptitudes of an engineer with an understanding of the reactions of people in business systems. About one half of the program of study for the B.S.E. degree consists of basic science and engineering courses, accompanied by studies in the humanities. The rest of the work is in areas such as plant analysis work, compensation, data processing, operations research, engineering economy, production engineering, probability and statistics, organization and management, including the use of new mathematical techniques for solving industrial problems. As an aid to education, the department has well-equipped demonstration facilities, laboratories, and digital and analog computers.

## REQUIREMENTS

Candidates for the degree B.S.E. (Ind. E.)—Bachelor of Science in Engineering (Industrial Engineering)—are required to complete the following program:

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | HOURS |
|---|---|
| English, Groups II and III | 4 |
| Econ. 401 | 3 |
| Eng. Mech. 310, Statics and Stresses | 4 |
| Eng. Mech. 343, Dynamics | 3 |
| Chem.-Met. Eng. 250, Principles of Engineering Materials | 3 |
| Chem.-Met. Eng. 270, Metals and Alloys | 3 |
| Eng. Graphics 104, Geometry of Engineering Drawing | 2 |
| Elec. Eng. 316, Circuit Analysis and Electronics | 4 |
| Mech. Eng. 251, Manufacturing Processes I | 3 |
| Mech. Eng. 335, Thermodynamics I | 3 |
| Mech. Eng. 340, Dynamics of Machinery | 4 |
| Mech. Eng. 362, Machine Design I | 3 |
| Mech. Eng. 381, Manufacturing Processes II | 3 |
| Ind. Eng. 400, Industrial Management | 3 |
| Ind. Eng. 431, Management Control | 3 |
| Ind. Eng. 441, Production Control | 3 |
| Ind. Eng. 447, Plant Layout and Materials Handling | 3 |
| Ind. Eng. 451, Engineering Economy | 2 |
| Ind. Eng. 463, Work Methods and Measurements I | 3 |
| Ind. Eng. 472, Operations Research | 3 |
| Ind. Eng. 473, Data Processing | 3 |
| Accounting 271 | 3 |
| Bus. Ad., General 454, Industrial Cost Accounting | 3 |
| Math. 273, Elementary Computer Techniques | 1 |
| Math. 465, 466, Introduction to Statistics | 6 |
| Nontechnical electives | 7 |
| Technical electives* (including one Ind. Eng. course) | 10 |
| Total hours in Group B | 95 |

*A maximum of six hours of advanced air, army, or naval science (300 and 400 series) may be used as electives in this group.

REPRESENTATIVE SCHEDULE

For studies of the first year, see page 24

| THIRD SEMESTER | HOURS | FOURTH SEMESTER | HOURS |
|---|---|---|---|
| Math. 215 | 4 | Math. 216 | 4 |
| Eng. Graphics 104 | 2 | Chem.-Met. Eng. 250 | 3 |
| Physics 146 | 5 | Mech. Eng. 335 | 3 |
| Acctg. 271 | 3 | Ind. Eng. 400 | 3 |
| English, Group II | 2 | Bus. Ad., General 454 | 3 |
| | 16 | Math. 273 | 1 |
| | | | 17 |

| SUMMER SESSION | HOURS |
|---|---|
| Eng. Mech. 310 | 4 |
| Elective | 3 |
| | 7 |

| FIFTH SEMESTER | HOURS | SIXTH SEMESTER | HOURS |
|---|---|---|---|
| Math. 465 | 3 | Math. 466 | 3 |
| Eng. Mech. 343 | 3 | Ind. Eng. 451 | 2 |
| Econ. 401 | 3 | Mech. Eng. 340 | 4 |
| Mech. Eng. 251 | 3 | Ind. Eng. 472 | 3 |
| English, Group III | 2 | Chem.-Met. Eng. 270 | 3 |
| Ind. Eng. 473 | 3 | Elective | 2 |
| | 17 | | 17 |

| SEVENTH SEMESTER | HOURS | EIGHTH SEMESTER | HOURS |
|---|---|---|---|
| Ind. Eng. 441 | 3 | Ind. Eng. 431 | 3 |
| Ind. Eng. 463 | 3 | Ind. Eng. 447 | 3 |
| Mech. Eng. 362 | 3 | Elec. Eng. 316 | 4 |
| Mech. Eng. 381 | 3 | Electives | 7 |
| Electives | 5 | | 17 |
| | 17 | | |

## MATERIALS ENGINEERING

*Program Adviser:* Professor Van Vlack, 4215 East Engineering

Materials Engineering and Materials Science have received an extensive emphasis within the past few years. Many of the major engineering schools have followed the University's lead in offering such curricula because, with the rapid development of new and better materials to meet the more exacting demands of industry and government agencies, there has developed a demand for engineers with a sound understanding of materials, and the factors that determine their various properties.

Materials engineers must have a sound foundation in physics and chemistry, as well as in engineering and in the materials used and manufactured by industry. They must also understand the utility, properties, and applications of materials such as metals, alloys, cements, plastics, ceramics, and protective coatings. They are particularly valuable in manufacturing plants where it is frequently desirable to replace present materials for the purpose of improving the product, reducing costs, reducing service failures, or because of shortages of specific raw materials. They find opportunities in the development of new products, specification of new materials, or combinations of these for existing products, development of new applications, or in the sales field. This program, as designed, also offers work in specifications, methods of fabrication, corrosion, high-temperature properties of metals, and stress analysis.

The program of studies offered by the Materials Engineering curriculum also provides a sound basis for advanced research in materials, an area that is fast becoming one of the most important fields of engineering activity. (See Engineering Materials, graduate studies.) This has led to the discovery of new materials and to the improvement of properties of existing materials.

## REQUIREMENTS

Candidates for the degree B.S.E. (Mat.E.)—Bachelor of Science in Engineering (Materials Engineering)—are required to complete the following program:

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | HOURS |
|---|---|
| **Basic Science and Mathematics** | |
| Advanced chemistry, to include such subjects as principles of physical chemistry, organic chemistry, and quantitative analysis* | 17 or 18 |
| Computer Techniques, Math. 273 | 1 |
| Electives* (see Note 1) | 4 or 5 |
| **Engineering Sciences** | |
| Thermodynamics and Rate Processes through Chem.-Met. Eng. 341 or Sci. Eng. 340 (see Note 2) | 15 |
| Engineering Materials | |
| Chem.-Met.Eng. 350, Structure of Solids | 3 |
| Chem.-Met. Eng. 450, Ceramic Materials | 4 |
| Chem.-Met. Eng. 451, Introduction to High Polymers | 4 |
| Chem.-Met. Eng. 470, 471, Physical Metallurgy | 7 |
| Chem.-Met. Eng. 472, X-ray Structure | 3 |
| Cognate engineering areas (must include Mechanics of Solids and Electrical Circuits)* | 14 |

*All electives must receive the advance approval of the program adviser.

Note 1: Differential equations, statistics, computer programming, and 300-level courses in Physics and Chemistry.

Note 2: Most commonly the students will take Chem.-Met. Eng. 200, 230, 341. Another possibility includes Sci. Eng. 330 and 340 and additional work in Materials Processing.

| | HOURS |
|---|---|
| **Engineering Design** | |
| Sequence of 2 or more courses which terminate with design courses, such as one of the following: Chem.-Met. Eng. 480, 481, Mech. Eng. 460, or Elec. Eng. 470* | 6 |
| **Elections in the humanities, arts, and social sciences** | |
| (At least four credit hours of literature; other elections must include courses in at least two of the following fields: anthropology, classical studies, economics, geography, history of art, history, journalism, music, languages, political science, philosophy, psychology, sociology, speech)* | 16 |
| Total hours in Group B | 95 |

## MATHEMATICS

*Program Co-advisers:* Assistant Professors Goldberg and Hedstrom, 347A West Engineering; Professor Hadley J. Smith, 312A West Engineering

The mathematics program in the College of Engineering provides the student with an opportunity to extend his knowledge of the language of the scientist, and to become more proficient in the application of mathematical reasoning to the formulation and solution of scientific problems in engineering. This program recognizes the ever-increasing demand that the changing physical and economic world imposes on the engineer. It therefore seeks to make available to him the knowledge with which he will be better able to understand and create the complex mathematical models which represent that world.

Many students, who are candidates for degrees in engineering programs of other fields, elect additional courses and qualify for the award of a degree in mathematics as well (see Requirements for Graduation).

### REQUIREMENTS

Candidates for the degree B.S.E. (Math.)—Bachelor of Science in Engineering (Mathematics)—are required to complete the following program:

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | HOURS |
|---|---|
| English, Groups II and III | 4 |
| Eng. Graphics 104 | 2 |
| Math. 273 | 1 |
| Chem.-Met. Eng. 250, Principles of Engineering Materials | 3 |
| Mech. Eng. 252, Engineering Materials and Manufacturing Processes | 2 |

*All electives must receive the advance approval of the program adviser.

| | HOURS |
|---|---|
| Math. 450 or 451, Advanced Calculus | 4 |
| Electives in the humanities, social sciences, and philosophy (see the *Announcement* of the College of Literature, Science, and the Arts for the basic courses in these fields of knowledge) | 12 |
| Eng. Mech. 208 or 218 | 3 |
| Eng. Mech. 210 or 219 | 4 |
| Eng. Mech. 324 or 326 | 3 or 4 |
| Eng. Mech. 343 or 345 | 3 |
| Elec. Eng. 316, Circuit Analysis and Electronics | 4 |
| Mech. Eng. 335, Chem.-Met. Eng. 230, or Sci. Eng. 330, Thermodynamics | 3 |
| Electives in mathematics, to include work in approved advanced mathematics having applications to problems in the physical sciences | 11 |
| Electives in engineering analysis and design | 15 |
| Electives in science and engineering science | 11 or 12 |
| Electives* | 9 |
| Total hours in Group B | 95 |

The fifteen hours of electives in engineering analysis and design must constitute a sequence of courses which provide an understanding and a useful knowledge in a specific area of engineering, and should include at least one course involving laboratory measurements. Suggested areas of engineering in which these electives may be chosen follow:

**Aeronautical and Astronautical Engineering**
Aerodynamics: Aero. Eng. 320, 330, 420, 520, or 525
Aeropropulsion: Aero. Eng. 320, 330, 420, 430
Flight Structures: Aero. Eng. 314, 414, 441, 510
Mechanics of Flight: Aero. Eng. 420, 441, 442, 471

**Civil Engineering**
Structures: Civ. Eng. 312, 313, 415, 514, 512 or 445 or 612 or 614 or 613 or 611

**Chemical Engineering**
Chem.-Met. Eng. 341, 342, 343, 480, 481

**Electrical Engineering**
Computers: Elec. Eng. 220, 380, 465, 466; Philosophy 414, 415
Electronics: Elec. Eng. 220, 310, 330, 380

**Industrial Engineering**
Ind. Eng. 400, 441, 472, 473, 527 or 541 or 571

**Instrumentation Engineering**
Math. 448, Elec. Eng. 418, Instr. Eng. 510, 570, 571

**Mechanical Engineering**
Automotive Engineering: Mech. Eng. 336, 343, 471, 493 or 496, 463 or 556
Energy Control: Mech. Eng. 336, 371, 421, 437, 535
Manufacturing: Mech. Eng. 381, 417, 483, 517, 567
Mechanical Design: Mech. Eng. 340, 362, 460, 463, 541

**Meteorology and Oceanography**
Meteor. and Ocean. 408, 440, 441, 462, 541.

Further details of these options, and of options in other areas, can be obtained from the program advisers.

All electives must be approved by a program adviser.

*A maximum of six hours of advanced air, army, or naval science (300 and 400 series) may be used as electives in this group.

## MECHANICAL ENGINEERING

*Program Adviser:* Associate Professor Quackenbush, 3305 East Engineering

The scope of activity of mechanical engineering includes all aspects of the mechanics of equipment and processes used in the rapidly developing technical era in which we live. Mechanical engineers play a major role in our space program, in the design of both conventional and nuclear power plants, in the automotive field, in heating and air conditioning, refrigeration and cryogenics, and in the fields of automation, fluid machinery, production, and processing machinery, consumer goods and appliances. They have responsibility for research, design, development, testing, control, and manufacture in these many and diverse fields. Many mechanical engineering graduates assume positions of management, while others prefer a career along technical and professional lines.

Because a mechanical engineer might work in any one of these fields, an academic program has been planned which offers a challenging and basic education. It is designed to provide a knowledge of the basic physical sciences, and to encourage the development of ingenuity for the purpose of creating well-engineered solutions to technological problems.

A basic science program in physics, chemistry, and mathematics, an engineering science program in thermodynamics, fluid mechanics, heat transfer, solid mechanics, dynamics, materials, and electronics integrated with laboratory experience in measurement, and studies in design and manufacturing, will prepare him equally well for any of the fields of application. The program includes a number of both technical and nontechnical electives which permit the student to undertake further studies in an area of particular interest.

Students who do well in their undergraduate program are encouraged to consider graduate work, and may take some of their electives in preparation for graduate study. Information and assistance regarding fellowships and assistantships for graduate study may be obtained in the Office of the Department of Mechanical Engineering. Some students may wish to work simultaneously for a second bachelor's degree in another program in accordance with the requirements presented under Requirements for Graduation.

### REQUIREMENTS

Candidates for the degree B.S.E.(M.E.)—Bachelor of Science in Engineering (Mechanical Engineering)—are required to complete the following:

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | HOURS |
|---|---|
| Electives in humanities, arts, and social sciences | 11 |
| English, Groups II and III | 4 |
| Econ. 401* Modern Economic Society | 3 |
| Chem.-Met. Eng. 250, Principles of Engineering Materials | 3 |
| Chem.-Met. Eng. 270, Metals and Alloys | 3 |
| Eng. Graphics, 104 | 2 |
| Eng. Mech. 208, Statics | 3 |
| Eng. Mech. 210, Mechanics of Material | 4 |
| Eng. Mech. 212, Laboratory in Mechanics of Material | 1 |
| Eng. Mech. 324, Fluid Mechanics | 3 |
| Eng. Mech. 343, Dynamics | 3 |
| Math. 273, Elementary Computer Techniques | 1 |
| Mech. Eng. 251, Manufacturing Processes I | 3 |
| Mech. Eng. 324, Fundamentals of Fluids Machinery | 4 |
| Mech. Eng. 335, Thermodynamics I | 3 |
| Mech. Eng. 336, Thermodynamics II | 4 |
| Mech. Eng. 340, Dynamics of Machinery | 4 |
| Mech. Eng. 362, Mechanical Design I | 3 |
| Mech. Eng. 381, Manufacturing Processes II | 3 |
| Mech. Eng. 460 or 462, Mechanical Design II*a* or II*b* | 4 |
| Mech. Eng. 471, Heat Transfer I | 4 |
| Elec. Eng. 316, Circuit Analysis and Electronics | 4 |
| Elec. Eng. 442, Motor Control and Electronics | 4 |
| Technical electives† | 14 |
| Total hours in Group B | 95 |

The technical electives requirement permits the student to pursue a sequence of courses reflecting his interest in a particular field such as automotive, air conditioning, design, fluids machinery, heat power (automotive and stationary power plants, including turbines, rockets, nuclear energy, etc.), instrumentation and control, manufacturing, mathematics and science, refrigeration, etc.

The student is encouraged to formulate his own sequence of elective courses, with the advice, and subject to the approval, of his adviser; example elective sequences for the fields listed above are available in the Mechanical Engineering office, 225 West Engineering Building.

*Econ. 103 and 104 may be substituted for Econ. 401 and 3 hours of electives in humanities, arts, and social sciences.

†This group of electives should include 3 credit hours of advanced mathematics, at least one advanced theory course, and one advanced laboratory in mechanical engineering. A maximum of 6 hours of advanced air, army, or naval science (300 and 400 series) may be used as electives in this group.

REPRESENTATIVE SCHEDULE

For studies of the first year, see page 24

| FIRST SEMESTER | HOURS | SECOND SEMESTER | HOURS |
|---|---|---|---|
| Math. 115 | 4 | Math. 116 | 4 |
| Chem. 104 | 4 | Chem. 105 | 4 |
| English 111 | 3 | Physics 145 | 5 |
| English 121 | 1 | English 112 | 2 |
| Eng. Graphics 101 | 3 | Eng. Graphics 104 | 2 |
| | 15 | | 17 |

| THIRD SEMESTER | | FOURTH SEMESTER | |
|---|---|---|---|
| Math. 215 | 4 | Math. 216 | 4 |
| Physics 146 | 5 | Eng. Mech. 210 | 4 |
| Eng. Mech. 208 | 3 | Eng. Mech. 212 | 1 |
| Chem.-Met. Eng. 250 | 3 | Mech. Eng. 251 | 3 |
| English, Group II | 2 | Math. 273 | 1 |
| | | Humanities | 3 |
| | 17 | | 16 |

| SUMMER SESSION | |
|---|---|
| Mech. Eng. 335 | 3 |
| Eng. Mech. 343 | 3 |
| | 6 |

| FIFTH SEMESTER | | SIXTH SEMESTER | |
|---|---|---|---|
| Eng. Mech. 324 | 3 | Mech. Eng. 324 | 4 |
| Mech. Eng. 336 | 4 | Elec. Eng. 316 | 4 |
| Mech. Eng. 381 | 3 | Advanced Math. | 3 |
| Mech. Eng. 340 | 4 | Mech. Eng. 362 | 3 |
| English, Group III | 2 | Humanities | 3 |
| | 16 | | 17 |

| SEVENTH SEMESTER | | EIGHTH SEMESTER | |
|---|---|---|---|
| Mech. Eng. 471 | 4 | Mech. Eng. 460 or 462 | 4 |
| Elec. Eng. 442 | 4 | Technical electives | 8 |
| Chem.-Met. Eng. 270 | 3 | Humanities | 5 |
| Econ. 401 | 3 | | 17 |
| Technical elective | 3 | | |
| | 17 | | |

## METALLURGICAL ENGINEERING

*Program Adviser:* Professor Sinnott, 4036 East Engineering

Metallurgical engineering is concerned with the production, processing, and utilization of metals and alloys. It is a broad field based on the sciences of chemistry and physics and closely related to the many other engineering disciplines.

To obtain the necessary breadth the basic program consists of courses in mathematics, chemistry, physics, the humanities, basic engineering sciences, and, in the fields of process, mechanical and physical metallurgy. Considerable choice is permitted the student in electives in related fields of science, engineering, and in specialized areas within the metallurgical area.

### REQUIREMENTS

Candidates for the degree B.S.E. (Met.E.)—Bachelor of Science in Engineering (Metallurgical Engineering)—are required to complete the following program:

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)
(A typical sequence is shown in the first half of the representative schedule below).

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | HOURS |
|---|---|
| **Basic Science** | |
| Advanced chemistry, to include such subjects as principles of physical chemistry, organic chemistry, and quantitative analysis | 15 |
| A course in electronic computers such as Math. 273 | 1 |
| **Chemical and Metallurgical Engineering Science** | |
| Introduction to Engineering Calculations, Chem.-Met. Eng. 200 | 3 |
| Thermodynamics I, Chem.-Met. Eng. 230 | 5 |
| Rate Processes I, Chem.-Met. Eng. 341 | 3 |
| Structure of Solids, Chem.-Met. Eng. 350 and 470 | 7 |
| **Electives*** | |
| 1. Electives in English (to include 4 credit hours of literature), humanities, social science, philosophy, languages, etc. | 14 |
| 2. Electives in law, business administration, and economics | 6 |
| 3. Electives in engineering science and analysis, to include mechanics and electrical science | 14 |
| 4. Electives in advanced science and mathematics | 7 |
| 5. Electives in professional metallurgical engineering subjects in the fields of process, mechanical, and physical metallurgy | 20 |
| Total hours in Group B | 95 |

### REPRESENTATIVE SCHEDULE

The number in parentheses preceding course name designates the group under Electives above.

| FIRST SEMESTER | HOURS | SECOND SEMESTER | HOURS |
|---|---|---|---|
| English 111 | 3 | Math. 116 | 4 |
| Eng. Graphics 101 | 3 | English 112, 121 | 3 |
| Chem. 107 | 5 | Physics 145 | 5 |
| Math. 115 | 4 | (1) Humanities | 4 |
| | 15 | | 16 |

*Courses up to four hours of advanced ROTC work will be considered for use as electives where appropriate.

| THIRD SEMESTER | HOURS |
|---|---|
| Physics 146 | 5 |
| Math. 215 | 4 |
| Chem.-Met. Eng. 200 | 3 |
| Math. 273 | 1 |
| (3) Eng. Mech. 310 | 4 |
| | 17 |

| FOURTH SEMESTER | HOURS |
|---|---|
| Math. 216 | 4 |
| Chem.-Met. Eng. 230 | 5 |
| Chem. 265 | 4 |
| (3) Eng. Mech. 343 | 3 |
| (1) English, Group II | 2 |
| | 18 |

| FIFTH SEMESTER | |
|---|---|
| Chem. 266 | 4 |
| (5) Chem.-Met. Eng. 370 | 3 |
| (4) Math. 404 | 3 |
| (3) Elec. Eng. 316 | 4 |
| Acctg. 271 | 3 |
| | 17 |

| SIXTH SEMESTER | |
|---|---|
| Chem. 220 | 3 |
| Chem.-Met. Eng. 341 | 3 |
| Chem.-Met. Eng. 350 | 3 |
| (4) Math., Physics, or Chem. | 4 |
| (3) Elective | 3 |
| | 16 |

| SEVENTH SEMESTER | |
|---|---|
| Chem.-Met. Eng. 470 | 4 |
| (2) Econ. 401 | 3 |
| Chem. 346 | 4 |
| (1) English, Group III | 2 |
| (1) Humanities | 2 |
| (5) Chem.-Met. Eng. 472 | 3 |
| | 18 |

| EIGHTH SEMESTER | |
|---|---|
| (5) Chem.-Met. Eng. 471 | 3 |
| (5) Chem.-Met. Eng. 477 | 3 |
| (5) Chem.-Met. Eng. 489 | 4 |
| (5) Chem.-Met. Eng. 390 | 4 |
| (1) Humanities | 4 |
| | 18 |

## METEOROLOGY

*Program Adviser:* Professor Dingle, 5062 East Engineering

The increasing recognition of the importance of weather and climate in a wide range of engineering problems has created a demand for engineers with a knowledge of meteorology and the ability to apply it to specific problems. There is a need for qualified engineering meteorologists, both men and women, in industry, government, teaching, research, and private practice—a need which gives every evidence of continuing for years to come.

Weather forecasting has traditionally been the main occupation of meteorologists, but modern meteorology encompasses a much wider range of activities and interests. In the planning of a large industrial plant the engineering meteorologist may be called upon to evaluate the proposed location, plant processes, stack characteristics, etc., in order to avoid or minimize air pollution problems. In the design of towers or suspension bridges, the dynamic wind loadings on the structure for that region and terrain must be studied and estimated. In transportation, whether by land, water, or air, weather is often the determining factor in maintaining efficient operation. Engineering meteorology has important application in many other areas, such as vehicle design; electrical power and natural gas dispatching; air conditioning; nuclear power plant design, location, and operation; cooling tower design; evaluation and prevention of weathering of materials; design of snow clearance heating systems; hydroelectric power development; solar energy use; and analysis of planetary atmospheres.

## REQUIREMENTS

Candidates for the degree B.S.E. (Meteor.)—Bachelor of Science in Engineering (Meteorology)—are required to complete the following program:

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | HOURS |
|---|---|
| English, Groups II and III | 4 |
| Chem.-Met. Eng. 250, Principles of Engineering Materials | 3 |
| Eng. Graphics 102, Descriptive Geometry | 3 |
| Eng. Mech. 208, Statics | 3 |
| Eng. Mech. 210, Mechanics of Material | 4 |
| Eng. Mech. 324, Fluid Mechanics | 3 |
| Eng. Mech. 343, Dynamics | 3 |
| Sci. Eng. 330, Thermodynamics | 3 |
| Sci. Eng. 340, Rate Processes | 3 |
| Elec. Eng. 215, Network Analysis | 3 |
| Elec. Eng. 320, Electromagnetics and Energy Conversion | 4 |
| Ind. Eng. 472, Operations Research | 3 |
| Math. 403 or 404, Differential Equations | 3 |
| M. & O. 412, Physical Climatology | 3 |
| M. & O. 432, Atmospheric Thermodynamics and Radiation | 3 |
| M. & O. 440, Principles of Weather Analysis | 3 |
| M. & O. 441, Laboratory in Weather Analysis I | 3 |
| M. & O. 445, Dynamic Meteorology | 3 |
| M. & O. 452, Physical Meteorology | 3 |
| M. & O. 462, Meteorological Instrumentation | 3 |
| M. & O. 470, Applied Meteorology | 2 |
| M. & O. 472, Hydrometeorological Design | 2 |
| M. & O. 475, Meteorological Analysis and Design Criteria | 2 |
| Civ. Eng. 420, Hydrology | 3 |
| Electives in mathematics, engineering science, physical science, and biological science* | 10 |
| Electives in humanities and social sciences | 13 |
| Total hours in Group B | 95 |

With the assistance of his adviser, each student is expected to draw up his own program of studies which may include not only the required courses in meteorology but also one or more sequences of related courses in the humanities and social sciences and in such areas as instrumentation, electronics, statistics, high-speed computation, geophysics, operations analysis, upper atmosphere analysis, water resources, air sanitation, or some other appropriate area.

*A maximum of four hours of advanced air, army, or naval science (300 and 400 series) may be used as electives in this group.

REPRESENTATIVE SCHEDULE

For studies of the first year, see page 24

| THIRD SEMESTER | HOURS |
|---|---|
| Math. 215 | 4 |
| Physics 146 | 5 |
| Eng. Mech. 208 | 3 |
| English, Group II | 2 |
| Chem.-Met. Eng. 250 or elective | 3 |
| | 17 |

| FOURTH SEMESTER | HOURS |
|---|---|
| Math. 216 | 4 |
| Eng. Graphics 102 | 3 |
| Elec. Eng. 215 | 3 |
| Eng. Mech. 210 | 4 |
| Electives | 4 |
| | 18 |

| FIFTH SEMESTER | |
|---|---|
| Sci. Eng. 330 | 3 |
| Eng. Mech. 324 | 3 |
| M. & O. 432 | 3 |
| M. & O. 440 | 3 |
| M. & O. 441 | 3 |
| Elective | 3 |
| | 18 |

| SIXTH SEMESTER | |
|---|---|
| Math. 403 or 404 | 3 |
| Eng. Mech. 343 | 3 |
| Sci. Eng. 340 | 3 |
| M. & O. 445 | 3 |
| M. & O. 452 | 3 |
| English, Group III | 2 |
| | 17 |

| SEVENTH SEMESTER | |
|---|---|
| Elec. Eng. 320 | 4 |
| M. & O. 412 | 3 |
| M. & O. 462 | 3 |
| M. & O. 472 | 2 |
| Civ. Eng. 420 | 3 |
| Elective | 3 |
| | 18 |

| EIGHTH SEMESTER | |
|---|---|
| Ind. Eng. 472 | 3 |
| M. & O. 470 | 2 |
| M. & O. 475 | 2 |
| Electives | 10 |
| | 17 |

## NAVAL ARCHITECTURE AND MARINE ENGINEERING

*Program Advisers:* Option 1: Associate Professor Yagle, 448E West Engineering; Option 2: Professor West, 448A West Engineering; Option 3: Associate Professor Yagle, 448E West Engineering

This program is primarily arranged to train students in the analysis and design of ships and ship machinery. Such topics as the form, strength, stability, cost, and resistance and propulsion characteristics of ship hulls are included. Various types of propelling machinery, such as steam and gas turbines and oil engines as well as conventional boilers and nuclear reactors, are considered. Other items of concern include propellers, economic aspects of ship design, model testing and ship hydrodynamics, vibration, heat transfer, and piping system design and analysis.

The design of a modern ship encompasses many engineering fields; also, graduates of this department are called upon to handle diverse professional responsibilities. It is essential that the program include training in the fundamentals of the physical sciences, mathematics, human relations, and other nonengineering subjects. It is recognized that the undergraduate program cannot, in the time available, adequately treat all areas of importance. Graduate work, therefore, is strongly encouraged.

The undergraduate student elects one of three options, each of which leads to the degree B.S.E. (Nav.Arch.&Mar.E.) —Bachelor of Science in Engineering (Naval Architecture and Marine Engineering); he thus acquires competence in one division of the field while obtaining a good introduction to the rest. These options are:

**Option 1. Naval Architecture** relates to the design of ship hulls and includes such topics as form, strength, stability, arrangements, resistance, powering, and methods of preliminary design.

**Option 2. Marine Engineering** places emphasis on the design of various types of propelling and auxiliary machinery and on their relation to the ship as a whole.

**Option 3. Maritime Engineering Science** stresses preparation for research and provides a stronger grounding in basic engineering science with less emphasis on design than that found in the other options. It will be normal for students in this option to spend an extra semester and receive an additional B.S.E. degree in mathematics or engineering mechanics or to do graduate work toward an M.S.E. degree from this or other departments.

Students wishing to obtain an additional B.S.E. degree in aeronautical engineering may do so under a combined program which allows for substantial substitution of courses in one curriculum for those required in the other. (See item 4, page 39.)

Facilities for research work are provided in the ship model basin. The University also has an operating nuclear reactor and an extensive nuclear engineering graduate program. Thus, upon completion of the requirements for a B.S.E. (Nav.Arch.&Mar.E.) degree, the student may continue with a nuclear engineering graduate program.

The department is in constant touch with the country's ship design offices, shipyards, and ship operators, and it is able to aid its graduates in obtaining positions in the various lines mentioned.

## REQUIREMENTS

Candidates for the degree B.S.E.(Nav.Arch.&Mar.E.)—Bachelor of Science in Engineering (Naval Architecture and Marine Engineering)—are required to complete the following:

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | HOURS |
|---|---|
| Chem.-Met. Eng. 250. Principles of Engineering Materials | 3 |
| Eng. Graphics 104, Geometry of Engineering Drawing | 2 |
| English, Groups II and III | 4 |
| Math. 273, Elementary Computer Techniques | 1 |

| | HOURS |
|---|---|
| Mathematics (additional work beyond Math. 216) | 3 |
| Econ. 401 | 3 |
| Eng. Mech. 208, Statics | 3 |
| Eng. Mech. 210, Mechanics of Material | 4 |
| Eng. Mech. 212, Laboratory in Mechanics of Material | 1 |
| Eng. Mech. 324, Fluid Mechanics | 3 |
| Eng. Mech. 343, Dynamics | 3 |
| Mech. Eng. 335, Thermodynamics I | 3 |
| Elec. Eng. 316, Circuit Analysis and Electronics | 4 |
| Nav. Arch. 200, Introduction to Practice | 2 |
| Nav. Arch. 201, Form Calculations and Static Stability I | 3 |
| Nav. Arch. 310, Structural Design I | 3 |
| Nav. Arch. 331, Marine Auxiliary Machinery | 3 |
| Nav. Arch. 420, Resistance, Propulsion, and Propellers | 5 |
| Electives in humanities and social sciences | 9 |
| Options 1, 2, or 3 | 33 |
| Total hours in Group B | 95 |

One of the following options should be selected by the student before the second semester of his sophomore year:

1. NAVAL ARCHITECTURE. *Adviser:* Associate Professor Yagle

| | |
|---|---|
| Mech. Eng. 252, Engineering Materials and Manufacturing Processes | 2 |
| Mech. Eng. 337, Mechanical Engineering Laboratory | 2 |
| Mech. Eng. 362, Machine Design I | 3 |
| Eng. Mech. 411, Structural Mechanics | 3 |
| Nav. Arch. 300, Form Calculations and Static Stability II | 2 |
| Nav. Arch. 330, Marine Propulsion Machinery | 3 |
| Nav. Arch. 400, Shipbuilding Contracts and Cost Estimating | 2 |
| Nav. Arch. 410, Stress Analysis of Ship Structures | 2 |
| Nav. Arch. 440, Ship Dynamics | 2 |
| Nav. Arch. 446, Theory of Ship Vibrations I | 3 |
| Nav. Arch. 470, Ship Design I | 3 |
| Nav. Arch. 471, Ship Design II | 2 |
| Nav. Arch. 472, Structural Design II | 2 |
| Free elective | 2 |
| | 33 |

2. MARINE ENGINEERING. *Adviser:* Professor West

| | |
|---|---|
| Mech. Eng. 252, Engineering Materials and Manufacturing Processes | 2 |
| Mech. Eng. 336, Thermodynamics II | 4 |
| Mech. Eng. 362, Machine Design I | 3 |
| Mech. Eng. 471, Heat Transfer I | 4 |
| Eng. Mech. 411, Structural Mechanics | 3 |
| Elec. Eng. 442, Motor Control and Electronics | 4 |
| Nuc. Eng. 400, Elements of Nuclear Engineering | 3 |
| Nav. Arch. 430, Design of Marine Power Plants I | 2 |
| Nav. Arch. 446, Theory of Ship Vibrations I | 3 |
| Nav. Arch. 473, Design of Marine Power Plants II | 3 |
| Free elective | 2 |
| | 33 |

3. MARITIME ENGINEERING SCIENCE. *Adviser:* Associate Professor Yagle

| | HOURS |
|---|---|
| Math. 450, Advanced Mathematics for Engineers | 4 |
| Nav. Arch. 330, Marine Propulsion Machinery | 3 |
| Eng. Mech. 403, Experimental Mechanics | 2 |
| | — |
| | 9 |

Either of the following two sequences:

| | |
|---|---|
| Eng. Mech. 412, Intermediate Mechanics of Material | 3 |
| Eng. Mech. 441, Intermediate Mechanics of Vibrations | 3 |
| | — |
| *or* | |
| Eng. Mech. 411, Structural Mechanics | 3 |
| Nav. Arch. 446, Theory of Ship Vibrations I | 3 |
| | — |
| | 6 |

Eighteen hours of technical electives, at least 12 of which are chosen from the following list. Of the 12 hours chosen from the list, a minimum of 4 hours must be in mathematics and naval architecture, respectively.

| | |
|---|---|
| Ind. Eng. 472, Operations Research | 3 |
| Instr. Eng. 510, Applications of the Electronic Differential Analyzer I | 3 |
| Instr. Eng. 570, Principles of Automatic Control | 3 |
| Instr. Eng. 571, Automatic Control Laboratory | 1 |
| Eng. Mech. 422, Intermediate Mechanics of Fluids | 3 |
| Math. 513, Introduction to Matrices | 3 |
| Math. 440, Vector Analysis | 2 |
| Math. 447, Modern Operational Mathematics | 2 |
| Math. 473, Introduction to Digital Computers | 3 |
| Math. 552, Fourier Series and Application | 3 |
| Physics 305, Modern Physics | 2 |
| Aero. Eng. 425, Principles of Aerodynamics | 3 |
| Mech. Eng. 471, Heat Transfer I | 4 |
| Nav. Arch. 410, Stress Analysis of Ship Structures | 2 |
| Nav. Arch. 430, Design of Marine Power Plants I | 2 |
| Nav. Arch. 440, Ship Dynamics | 2 |
| Nav. Arch. 470, Ship Design I | 3 |
| Nav. Arch. 630, Nuclear Ship Propulsion | 3 |
| Nuc. Eng. 400, Elements of Nuclear Engineering | 3 |

## REPRESENTATIVE SCHEDULE

For studies of the first year, see page 24.

| THIRD SEMESTER | HOURS | FOURTH SEMESTER | HOURS |
|---|---|---|---|
| Math. 215 | 4 | Math. 216 | 4 |
| Physics 146 | 5 | Eng. Mech. 210 | 4 |
| Eng. Mech. 208 | 3 | Eng. Mech. 212 | 1 |
| Nav. Arch. 200 | 2 | Nav. Arch. 201 | 3 |
| Eng. Graphics 104 | 2 | Chem.-Met. Eng. 250 | 3 |
| Math. 273 | 1 | English, Group II | 2 |
| | — | | — |
| | 17 | | 17 |

| SUMMER SESSION | HOURS Option 1 | 2 | 3 |
|---|---|---|---|
| Mech. Eng. 335 | 3 | 3 | 3 |
| Math. | 3 | 3 | 3 |
| Mech. Eng 252 | 2 | 2 | – |
| Humanities | – | – | 2 |
| | 8 | 8 | 8 |

| FIFTH SEMESTER | Option 1 | 2 | 3 |
|---|---|---|---|
| Elec. Eng. 316 | 4 | 4 | 4 |
| Eng. Mech. 324 | 3 | 3 | 3 |
| Eng. Mech. 343 | 3 | 3 | 3 |
| Mech. Eng. 336 | – | 4 | – |
| Mech. Eng. 337 | 2 | – | – |
| Nav. Arch. 300 | 2 | – | – |
| Nav. Arch. 310 | – | 3 | – |
| Nav. Arch. 330 | 3 | – | 3 |
| Technical electives | – | – | 4 |
| | 17 | 17 | 17 |

| SIXTH SEMESTER | HOURS Option 1 | 2 | 3 |
|---|---|---|---|
| Eng. Mech. 403 | – | – | 2 |
| Eng. Mech. 411 | 3 | 3 | – |
| Math 450 | – | – | 4 |
| Mech. Eng. 362 | 3 | 3 | – |
| Mech. Eng. 471 | – | 4 | – |
| Nav. Arch. 310 | 3 | – | 3 |
| Nav. Arch. 331 | 3 | 3 | 3 |
| Nav. Arch. 420 | 5 | – | 5 |
| Humanities | – | 2 | – |
| Free elective | – | 2 | – |
| | 17 | 17 | 17 |

| SEVENTH SEMESTER | Option 1 | 2 | 3 |
|---|---|---|---|
| Econ. 401 | – | – | 3 |
| Elec. Eng. 442 | – | 4 | – |
| Nav. Arch. 400 | 2 | – | – |
| Nav. Arch. 410 | 2 | – | – |
| Nav. Arch 420 | – | 5 | – |
| Nav. Arch. 430 | – | 2 | – |
| Nav. Arch. 440 | 2 | – | – |
| Nav. Arch. 446 | 3 | 3 | – |
| Nav. Arch. 470 | 3 | – | – |
| Humanities | 4 | 3 | 4 |
| Technical electives | – | – | 10 |
| | 16 | 17 | 17 |

| EIGHTH SEMESTER | Option 1 | 2 | 3 |
|---|---|---|---|
| Econ. 401 | 3 | 3 | – |
| English, Group III | 2 | 2 | 2 |
| Nav. Arch. 471 | 2 | – | – |
| Nav. Arch. 472 | 2 | – | – |
| Nav. Arch. 473 | – | 3 | – |
| Nuc. Eng. 400 | – | 3 | – |
| Humanities | 5 | 4 | 3 |
| Free elective | 2 | – | – |
| Technical electives | – | – | 10 |
| | 16 | 15 | 15 |

## PHYSICS

*Program Co-advisers:* Professor Wolfe, 4063 Randall; Professor Enns, 312B West Engineering

The rapid advance in physics and its applications in industry have developed increasing demands for applied physicists. This program is intended to meet the demand and usually leads to activities in research, development, or teaching.

Students who are candidates for degrees in engineering programs often elect additional courses in this program and qualify for graduation with a degree in physics as well. See Requirements for Graduation.

## REQUIREMENTS

Candidates for the degree B.S.E. (Phys.)—Bachelor of Science in Engineering (Physics)—are required to complete the following program:

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | HOURS |
|---|---|
| English, Groups II and III | 4 |
| Modern language | 8 |
| Chem.-Met. Eng. 250, Principles of Engineering Materials | 3 |
| Chem. 265, Principles of Physical Chemistry | 4 |
| Math. 273, Elementary Computer Techniques | 1 |
| Math. 450, Advanced Mathematics for Engineers | 4 |
| Eng. Mech. 208, Statics | 3 |
| Eng. Mech. 210, Mechanics of Material | 4 |
| Eng. Mech. 343, Dynamics, or Physics 401, Intermediate Mechanics | 3 |
| Eng. Mech. 324, Fluid Mechanics, or Physics 411, Mechanics of Fluids | 3 |
| Elec. Eng. 210, Circuits I | 4 |
| Elec. Eng. 310, Circuits II | 4 |
| Mech. Eng. 252, Engineering Materials and Manufacturing Processes | 2 |
| Physics 405, Intermediate Electricity and Magnetism | 3 |
| Physics 406, Heat and Thermodynamics, or a course in engineering thermodynamics | 3 |
| Physics 453, Atomic and Molecular Structure | 3 |
| Physics 455, Electron Tubes | 4 |
| Group options and electives | 35 |
| Total hours in Group B | 95 |

Group options and electives are to be selected with the advice and consent of the program adviser in accordance with the distribution of hours as listed below. For the group of engineering electives, each student is expected to complete a planned sequence including analysis, design, and systems in some particular field of engineering.

| | HOURS |
|---|---|
| Physics | 7 |
| Mathematics | 3 |
| Engineering electives | 12 |
| From economics, geography, history, philosophy, political science, psychology, or sociology | 6 |
| Electives* | 7 |
| | 35 |

*A maximum of four hours of advanced courses in air, army, or naval science (300 and 400 series) may be used as electives in this group.

## SCIENCE ENGINEERING

*Program Adviser:* Professor Bigelow, 4213 East Engineering

Recent trends in engineering have been characterized by an increasing emphasis on science, with many revolutionary advances in the scientfic bases of the older fields of engineering as well as a spectacular expansion of engineering into many new fields such as nuclear energy, instrumentation, operations and systems analysis, and space technology.

The Science Engineering program is designed to develop engineers having the versatility and flexibility required to meet the needs of our expanding and changing technology by providing a broad basis of training in the fundamental principles with a sound knowledge of the application of the scientific method to engineering design and analysis.

Students completing the Science Engineering program have a scientific background equivalent to that obtained in many programs leading to the master's degree, but they are not required to complete all of the specialized courses required for the bachelor's degree in most traditional engineering programs. In recognition of the increasing contributions of scientists and engineers to the political, social, cultural, and philosophical aspects of modern civilization, the Science Engineering program also affords an opportunity for electing a number of courses in humanities, social sciences, and foreign languages.

### REQUIREMENTS

Candidates for the degree B.S.E. (Sci.E.) —Bachelor of Science in Engineering (Science Engineering) — are required to complete the program outlined below. Among the Group A subjects, the Unified Science sequence of accelerated and integrated preparatory courses beginning with Mathematics 185, Physics 153, and Chemistry 194 are strongly recommended for those students who are qualified. The representative schedule on pages 78-79 is expressed in terms of this sequence. The many alternative sequences of preparatory courses with the same terminal level of accomplishment are acceptable, of course, but they add hours to the preparatory portion of the illustrated schedule. The mathematics sequence beginning with Mathematics 115 adds 4 hours; the physics sequence beginning with Physics 145 adds 2 hours; the chemistry sequence beginning with Chemistry 107 adds 1 hour; and the chemistry sequence beginning with Chemistry 103 adds 4 hours.

For the engineering science courses of the Group B subjects, the special sequences of courses beginning with Engineering Mechanics 218, Electrical Engineering 215, and Science Engineering 330 are normally recommended; however, certain equivalent courses may be substituted for these, with the approval of the program adviser, when it is advantageous in developing a program to meet the special interests of individual students.

A unique feature of the Science Engineering program is the unusual amount of freedom allowed in the selection of advanced engineering courses. The engineering electives, together with the unspecified electives and the electives in advanced mathematics, chemistry, physics, and thermodynamics, may be selected so as to provide a high degree of competence in one of the traditional fields of engineering; or they may be used to combine courses from several fields to obtain training in some special phase of engineering that is common to several of the traditional fields of engineering. This elective freedom frequently makes it possible for a student to obtain two bachelor's degrees in engineering with only a little extra course work or to prepare for graduate work in almost any of the professional engineering fields. Science Engineering counselors work closely with the students and with counselors in other engineering programs to select courses best suited for special purposes.

A. SUBJECTS TO BE ELECTED OR EQUIVALENT PROFICIENCIES TO BE DEMONSTRATED (see page 40)

B. PROFESSIONAL AND ADVANCED SUBJECTS AND ELECTIVES

| | | HOURS |
|---|---|---|
| Engineering science, including engineering materials, statics, strength of materials, dynamics, fluid mechanics, thermodynamics, electromagnetics and energy conversion, network analysis, electronics and systems, rate processes | | 36 |
| Electives in engineering, including at least one elective in design or analysis and at least one elective involving engineering laboratory | | 17 |
| Electives in mathematics, physics, chemistry, or thermodynamics, including Chemistry 195 or 265 and at least 3 hours of advanced mathematics | | 16 |
| Electives in English, history of art, philosophy, and at least 4 hours of literature | 6–10 | 20 |
| Electives in anthropology, economics, geography, history, journalism, political science, psychology, or sociology | 6–14 | |
| Electives in foreign language | 0–8 | |
| Electives* | | 6 |
| Total hours in Group B | | 95 |

REPRESENTATIVE SCHEDULE

(In terms of accelerated sequences)

| FIRST SEMESTER | HOURS | SECOND SEMESTER | HOURS |
|---|---|---|---|
| Math. 185 | 4 | Math. 186 | 4 |
| Physics 153 | 4 | Chem. 194 | 4 |
| Eng. Graphics 101 | 3 | English 112 | 2 |
| English 111 | 3 | Electives (humanities, soc. sci., language) | 6 |
| English 121 | 1 | | |
| | 15 | | 16 |

*Advanced air, army, or naval science (300 and 400 series) may be used as electives in this group.

| THIRD SEMESTER | HOURS |
|---|---|
| Math. 285 | 4 |
| Chem. 195 | 4 |
| Eng. Mech. 218 | 3 |
| Electives (humanities, soc. sci) | 7 |
| | — |
| | 18 |

| FOURTH SEMESTER | HOURS |
|---|---|
| Elective (math.) | 3 |
| Physics 154 | 4 |
| Eng. Mech. 219 | 4 |
| Elec. Eng. 215 | 3 |
| Electives (humanities, soc. sci.) | 4 |
| | — |
| | 18 |

| FIFTH SEMESTER | |
|---|---|
| Sci. Eng. 330 | 4 |
| Elec. Eng. 320 | 4 |
| Eng. Mech. 345 | 3 |
| Elective (math., chem., physics) | 4 |
| Elective (humanities, soc. sci.) | 3 |
| | — |
| | 18 |

| SIXTH SEMESTER | |
|---|---|
| Sci. Eng. 340 | 4 |
| Elec. Eng. 337 | 4 |
| Eng. Mech. 326 | 4 |
| Elective (math., chem., physics) | 2 |
| Elective (engineering) | 4 |
| | — |
| | 18 |

| SEVENTH SEMESTER | |
|---|---|
| Electives (engineering) | 6 |
| Elective (math., chem., physics) | 3 |
| Chem.-Met. Eng. 350 | 3 |
| Electives | 6 |
| | — |
| | 18 |

| EIGHTH SEMESTER | |
|---|---|
| Electives (engineering) | 7 |
| | — |
| | 7 |

# Special Fields

New developments in science and in the art of engineering are reflected in new courses offered by an alert faculty. Such courses may be elected under the system of group options and electives in the undergraduate program or in a program of advanced work in the Graduate School. Many of these special fields have been specifically mentioned under the various degree programs. Information regarding these fields and others in which the student may be interested will be made available upon request. Program advisers will assist any student in preparing a program to fit his particular desires.

## BIOENGINEERING

Opportunity to study in the new educational field of bioengineering is being offered to qualified students enrolled in the College of Engineering. The purpose is to provide an educational opportunity for engineering students to study the biological sciences along with the physical sciences, mathematics, and engineering sciences in order that they may apply the physical and engineering sciences with understanding to biological systems. It is intended to prepare an engineering student for a new professional area in which the engineer will find additional outlets for his analytical ability.

The new field of bioengineering is very broad. There are many areas of collaborative activity in investigation of biological systems, both basic and applied, involving the engineer and the biologist, where a knowledge of systems theory is required. Chemical reactions and transport, electrical behavior and response, fluid flow in biological systems, and biomechanics require quantitative analyses of component behavior. The complex coupling of components, involving advanced adaptive servo and signal theory, is further necessary to the understanding of biological system function and response. As biological systems are better understood, their complexities require a more sophisticated formulation that is a part of the most recent advances in engineering science. The advances in operations research provide a further approach to the problems associated with biological systems studies. There are no boundaries to the opportunities for the qualified engineer.

Plans are being developed for bioengineering to be available to students in the several professional departments of the College. Such students will be associated with educational programs in the College of Engineering, the College of Literature, Science, and the Arts, the Medical School, and the School of Public Health.

Students interested in exploring this opportunity for study should review their plans with their program advisers.

## COMMUNICATION SCIENCES

The program in Communication Sciences is concerned with understanding on a theoretical basis the communication and processing of information by both natural and artificial systems. Two general areas of study are particularly important to the communication sciences: (1) the technical study of natural and artificial languages as modes of communication, and (2) the investigation of information processing both in natural systems and in mathematical automata. In the technical study of languages, attention is given both to natural languages and to various types of artificial languages, including codes used in communciation systems, instructional and design languages for digital computers, and the formal languages of mathematical logic. In the investigation of information processing systems, attention is directed toward fixed and growing automata, adaptive systems, nerve nets, automatic speech recognizers, self-adaptive behavioral systems, and organized task groups.

A bachelor's degree is required before the student may specialize in communication sciences. Areas of concentration which are valuable as a background for graduate work in communication sciences are: mathematics, physics, electrical engineering, biology, psychology, philosophy, and linguistics. Students who are preparing for graduate study in the communication sciences should consult with the Chairman of the Committee on the degree program in Communication Sciences, Professor Gordon E. Peterson, 180 Frieze Building.

Undergraduate students may begin specialization in the communication sciences by electing one or more of the following courses: Com. Sci. 400, Foundations of the Communication Sciences; Math. 404, Differential Equations; Math. 425, Mathematical Theory of Probability.

## INSTRUMENTATION ENGINEERING

Instrumentation engineering is a program covering the dynamical aspects of systems engineering. This involves the principles and application of areas including measurement, information theory, data transmission, computers, feedback control, and random processes as they relate and are basic to systems in all fields of technology and science.

The best preparation can be achieved by completing the requirements for one of the undergraduate B.S.E. degree programs, the science engineering program being the most appropriate, followed by special work in instrumentation at the graduate level. See under M.S.E. degree programs and course listings.

Undergraduate students may start these special studies by electing one or more of the following courses: Instr. Eng. 570, Principles of Automatic Control I (*3*); Instr. Eng. 571, Automatic Control Laboratory I (*1*); Instr. Eng. 530, Probability in Instrumentation (*2*); Elec. Eng. 438, Electronics and Radio Communication (*4*); Math. 448, Operational Methods for Systems Analysis (*4*).

## NUCLEAR ENGINEERING

Nuclear engineering is concerned with the release, control, and utilization of energy from nuclear sources. These sources have new and unusual properties and present special problems to the engineer. At present the field requires men capable of developing new ideas and new concepts. More emphasis is therefore placed on advanced training in fundamental areas than on existing technology. The degree programs in nuclear engineering are offered only at the graduate level. Undergraduates interested in electing courses in the department should consult Professor Kikuchi or Assistant Professor Gyorey, 300 Automotive Engineering Laboratory.

Students who wish to acquire a background for the use of radiation in science and industry may elect Nuc. Eng. 470, 550, and 560. Students desiring a one-semester course in nuclear engineering should elect Nuc. Eng. 400.

Students planning to enter the nuclear engineering program should take, as undergraduates, courses in atomic and nuclear physics (Nuc. Eng. 470 or equivalent), advanced calculus (Math. 450 or 451 or equivalent), and electronics (Elec. Eng. 337 or Physics 455 or equivalent). Those entering without these prerequisites will be required to make up the deficiencies in addition to the thirty hours required for the master's degree. Courses in heat transfer (Mech. Eng. 471), electromagnetic field theory (Elec. Eng. 420), and use of digital computers (Math. 473) are also recommended as desirable preparation.

## RESERVE OFFICERS TRAINING CORPS

The objective of the ROTC is to train well-qualified officers for the armed forces.

Each entering male freshman enrolled in The University of Michigan has the opportunity to enroll in the Army ROTC, the Navy ROTC, or the Air Force ROTC if he meets the specific requirements of the respective unit. Enrollment is voluntary, but the University and the Armed Forces expect each student who enrolls to meet the full obligations accepted.

Each ROTC unit offers an eight-semester sequence of courses which may be carried as electives with the student's degree program in order to earn a Reserve or Regular commission along with the baccalaureate degree.

The student agrees to add to his own degree requirements the completion of the ROTC program in which he is enrolled as follows:

| Unit | ROTC<br>Program in which student is enrolled | Student agrees to add to his degree requirements for graduation | Credit allowed toward degree requirement as electives |
|---|---|---|---|
| Army or Air Force | 2-year basic | Completion of 2 years—(Fr.-Soph.)* | None |
| Army or Air Force | 2-year advanced (upon application and selection) | Completion of 2 years—(Jr.-Sr.) | See degree requirements of professional program elected |
| Navy | NROTC<br>Contract and Regular | Completion of 4 years† | See degree requirements of professional program elected |

*The University and the Professor of Miltary Science or the Professor of Air Science may jointly cancel this requirement whenever a valid reason for discontinuing the freshman-sophomore program is presented; Army ROTC cadets are normally expected to complete the basic pogram.

†Contract students may be permitted by the Professor of Naval Science to withdraw for valid reasons during the first two years.

The student completing four years of ROTC agrees to accept his commission as a condition of receiving his diploma.

Since there are minor variations among the three services, interested engineering students should study the pertinent information in this announcement, and if any questions arise consult the Professor of Military Science for further information about the Army; the Professor of Naval Science about the Navy; and the Professor of Air Science about the Air Force.

On permission to drop, refer to Election of Studies.

## AIR SCIENCE

**General Information.** The Department of Air Science offers four years of generalized Air Science studies in combination with non-ROTC courses all designed to prepare selected male officer candidates for commissioning in the United States Air Force. The sequence of courses provides understanding of national and international defense requirements; of the global mission and organization of the USAF; and of officer leadership and management responsibilities and skills. To comply with federal law concerning total hours of contact time, freshman and sophomore cadets in the basic program spend three class periods per academic week in Air Science or approved non-ROTC courses; juniors and seniors in the advanced program spend five hours per week in Air Science or approved non-ROTC courses; advanced cadets attend a twenty-eight-day summer training period at an active Air Force base, normally following the junior year. Enrollment in basic program courses is the same as for all University courses, with no commitment made to seek a commission; however, the student must be interviewed by the chairman of the Department of Air Science before registering for his first Air Science course. In the spring of the sophomore year a cadet may apply for the advanced program to earn a commission. Upperclass cadets may seek a commission in one of the following categories: pilot or navigator training (regardless of college academic major), engineering and science specialties, and other specialties. Graduates who apply and are selected for pilot or navigator training will serve three and one-half to four years on active duty following completion of flying training. Graduates entering nonflying positions serve on active duty for four years. Active service may be delayed in order to study for an advanced degree.

**Flying Activities.** Senior year cadets qualified and desiring active service pilot training receive in a Flight Instruction Program approximately thirty-six hours of dual/solo light plane instruction under a licensed civilian instructor, having opportunity also to earn a private pilot's license. They receive thirty hours of "ground school" work (see A.S. 401 listing below). When possible, local area orientation flights and overnight flights to active Air Force bases are made to familiarize cadets with Air Force life.

**Requirements for Enrollment.** A male student enrolled in the University who is a physically qualified citizen of the United States (or will become a citizen during his fourth semester) who can complete eight semesters of air science work prior to receiving his degree and who will meet all requirements for commissioning prior to his twenty-eighth birthday may enroll in the basic program. Students with prior military service may enroll above the entry level based upon evaluation of such military service by the Professor of Air Science. Women students may apply for enrollment in a noncommission-seeking status.

**Transfer Students.** Students who have completed one or more years of ROTC studies (Air Force, Army, or Navy) at any college-level institution or who have sufficient prior military service may enter the AFROTC program as late as the first semester of the junior year. They should contact the Professor of Air Science prior to registration week, if possible, in order that a tentative determination of eligibility may be made and to allow time for the Department of Air Science to procure records from the ROTC department with which previously enrolled.

**Alternates for ROTC Courses.** University courses have been substituted for approximately 45 per cent of the basic and advanced programs. In the fall of the freshman year and in the spring of the sophomore year students may designate from their own degree program courses one course (in mathematics, physical or natural or social sciences, foreign language, or humanities) as alternate for the *academic* portion of the Air Science course. Advanced cadets take non-ROTC courses in political geography, and international relations along with reduced time in Air Science classes, as specified in the respective listings of courses A.S. 401 and 402 below.

**Monetary Allowances** are paid to advanced cadets (3rd and 4th Air Science years) totaling approximately $275 per year plus aproximately $75 and a travel allowance for the summer training period.

**Uniforms and Books** are furnished to all Air Science cadets. Each advanced program cadet is measured for a fitted uniform which becomes a gift from the University on the date of his commissioning. A uniform deposit of $20 is required; it is refunded when Air Science studies are terminated.

**Commissions in the Regular Air Force.** Any AFROTC cadet designated a Distinguished AFROTC Cadet and who maintains his standing and becomes a Distinguished AFROTC Graduate may be commissioned in the Regular Air Force upon entering active service.

**Selective Service Deferment.** Basic program cadets are entitled to deferment after the first semester, based on enrollment in ROTC. Deferment of a cadet may be continued as late as one year beyond the completion of the fourth year of Air Science studies provided the cadet is still working to earn his degree and commission.

**Extracurricular Activities.** The Department of Air Science sponsors a rifle team and cadet work in Air Explorer training; it also cosponsors a triservice ROTC band. Selected cadets may become members of the local chapter of the national Arnold Air Society. Qualified cadets may participate in triservice honorary organizations.

**Program Modification.** In event proposed legislation becomes law, replacing the four-year AFROTC program with a two-year Air Force Officer Education Program, admission of freshmen probably will not occur in the first year of OEP phase-in, and A. S. 101 and 102 would be discontinued that year. A. S. 300 series is being revised fall semester 1964 to phase-in the 2-year program (See A. S. 301, 302). A. S. 400 series will be modified fall 1965 as a further step to meet the curriculum of the changed program.

COURSES OFFERED IN AIR SCIENCE

**101. Foundations of Leadership.** *(1).*
To be accompanied by approved non-ROTC course. Laboratory and seminar, 1 hour a week.

**102. Foundations of Aerospace Power.** *(2).*
Conflict in aerospace age; military instruments for national security; organization for national security; the Air Force as a profession; professional opportunities in the Air Force. Seminar, 2 hours a week; laboratory, 1 hour a week.

**201. Fundamentals of Aerospace Weapons.** *Prerequisite: A.S. 101, 102, or permission of department. (2).*
Introduction to aerospace missiles and aircraft, their propulsions systems; aerospace defense; modern targeting and electronic warfare; high explosive, nuclear, chemical, and biological warheads; and aerospace strategic and tactical operations with contemporary Air Force weapon systems. Also includes military implications of present and future space operations. Seminar, 2 hours a week; laboratory, 1 hour a week.

**202. Foundations of Leadership.** *Prerequisite: A.S. 101, 102, or permission of department. (1).*
To be accompanied by approved non-ROTC course. Laboratory and seminar, 1 hour a week.

**301. Growth and Development of Aerospace Power.** *Prerequisite: completion of 100 and 200 series courses in Air Science (or Military or Naval Science equivalent) and selection by department chairman. (3).*
The nature of military conflict; development of aerospace power; development of doctrine governing the employment of aerospace forces; the mission and organization of the USAF; employment of forces in general war, limited war, and actions short of war. Seminar 3 hours a week; 1 hour supervised research; laboratory, 1 hour a week.

**302. Growth and Development of Aerospace Power.** *Prerequisite: A.S. 301 or permission of department. (3)*
Evolution of the space program; the effects of solar geography on the space program; principles and problems affecting the use of orbits and trajectories; operating principles, characteristics, and problems associated with components of space vehicles; current and planned capabilities for space operations. Seminar 3 hours a week, 1 hour supervised research; laboratory, 1 hour a week.

**401. Global Relations.** *Prerequisite: A.S. 301, 302. (2).*

Weather, navigation. This academic work constitutes 30 hours of "ground school" for seniors in the Flight Instruction Program seeking pilot training, and is required for senior cadets who will be pilot training or navigator training applicants. Seniors not candidates for flying training may take this course or may arrange with the Professor of Air Science for permission to take an alternate University course which will enhance their officer qualifications. Seminar, 2 hours a week; laboratory, 1 hour a week; accompanied by Geography 435.

**402. Global Relations.** *Prerequisite: A.S. 401. (1).*

The AF officer, preparation for active service. Seminar, 1 hour a week; laboratory, 1 hour a week; accompanied by Pol. Sci. 160.

**403. Advanced Leadership Laboratory.** *Prerequisite: all laboratory work in 300 series Air Science courses. (1).*

Planning training activities for Basic and Air Science 3 cadets. Observing, evaluating, instructing, or otherwise directing subordinates in staff or operational situations. Required for senior cadets excused from enrolling in A. S. 401.

## MILITARY SCIENCE

Professor Harris; Assistant Professors Dahl, Roberts, and Wood. Department office, 131 North Hall.

**General Information.** The objective of the Army ROTC program is to produce junior officers who by their education, training, and inherent qualities are suitable for continued development as officers in the United States Army. ROTC graduates, after attaining a baccalaureate degree, are commissioned as second lieutenants in the Army Reserve. Outstanding ROTC cadets who are designated as Distinguished Military students may apply for a direct commission in the Regular Army (the same commission as given United States Military Academy graduates).

Regularly enrolled University of Michigan male students who meet the established physical, citizenship, age, and moral standards prescribed may enroll in the Army ROTC program. Enrollment in the ROTC is elective, and ROTC cadets are excused from the University requirement of two semesters of physical education. A cadet may drop ROTC, if he so desires, only during the first few weeks of the first semester. A cadet that remains in the ROTC after the dropout period authorized by his own college is required to complete four semesters of ROTC as a University degree requirement. This requirement can be waived only in exceptionally grave circumstances such as when a student is placed on academic probation.

In order for a cadet to continue into the advanced ROTC program (junior and senior years), he must have exhibited marked leadership potential. Thus, entrance into the advanced program is on an invitational basis, the cadet having the option to accept or decline. A cadet, having accepted the advanced program, is required to sign a contract to: (1) continue the ROTC program for the remaining four semesters; (2) accept a commission, if tendered; and (3) serve his military obligation of active duty and reserve duty as required by law.

The current military obligation is either (1) two years of active duty and four years in the Reserve, or (2) six months of active duty for training and seven and one-half years in the Reserve. ROTC graduates indicate their personal preference, but determination of length of tour of active duty is based upon the current needs of the Department of the Army. In the past, almost everyone received his preference.

Each cadet is required to attend a six-week ROTC Summer Camp, normally at the end of his junior year. Emphasis of training at summer camp is on leadership and field application of studies at the University.

ROTC graduates who desire to defer their tour of active duty in order to do graduate work at any accredited university may apply for an academic delay. Academic delays are given for one year and may be renewed for a maximum total of four years. To date, no University of Michigan ROTC graduate has been denied his request for delay or extension of delay.

**Branch Assignments.** During their senior year, cadets will be classified for branch assignment upon commissioning to one of the following branches in accordance with their leadership, aptitude, curriculum, interest, physical condition, and the nationwide needs of the Army:

**Arms.** Armor, Artillery, Infantry, Corps of Engineers, Signal Corps, (Physical qualifications for all of above are the same, somewhat more demanding than for the services listed below. Engineers and Signal are *both* an Arm and a Service.)

**Technical and Administrative Services.** Adjutant General's Corps, Army Security, Chemical Corps, Corps of Engineers, Finance Corps, Medical Service Corps, Military Intelligence, Military Police Corps, Ordnance Corps, Quartermaster Corps, Signal Corps, Transportation Corps. Though completion of the ROTC program does *not* lead directly to commissions in Medical Corps, Dental Corps, Chaplain's Corps, Judge Advocate General's Corps, or Veterinary Corps, students interested in these fields are encouraged to contact the Military Science Department personally as there are many cogent reasons for enrolling in the ROTC program.

**Advanced Standing.** Students with prior military service or prior ROTC training (high school or college) may receive advanced standing in the ROTC program. The many variables preclude a blanket statement of eligibility; thus, students should contact the Military Science Department personally for advanced standing determination.

**Pay and Allowances.** Pay and allowances begin with enrollment in the third year of military science and amount to approximately $265 for each of the last two years. In addition, the cadet receives approximately $117, plus travel expenses to and from summer camp, for the six-week summer camp.

**Uniforms, Texts, and Equipment.** All ROTC cadets are furnished a uniform and all texts and equipment without charge; however, a security deposit of $20 is required. The uniform furnished at the beginning of the third year is custom tailored and may be retained by the individual for active duty wear as an officer.

**Extracurricular Activities.** Cadets are free to elect as few or as many of the following activities as desired:

Army Rifle and Pistol Team—Range, rifle, or pistol, and ammunition available without charge.

ROTC Marching Band—Spring semester only, instruments furnished, attendance not required at Leadership Laboratory.

Pershing Rifles—A national honorary to promote leadership and comradeship through impeccable close order drill and fancy drill.

Scabbard and Blade—A national honorary.

**Course of Instruction.** The complete course of instruction comprising eight semesters plus summer camp is divided into four major blocks of instruction: (1) American Military History; (2) Operations, Tactics, and Techniques; (3) Logistics and Material; (4) School of the Soldier and Exercise of Command (Leadership Laboratory). The instructional objective of the Department of Military Science is to integrate the instruction under the four areas of military knowledge and skill into the progressive development of self-confidence, initiative, sense of responsibility, high moral standards, and leadership.

The Department of the Army has revised the course of instruction for the four-year period to include "academic substitution." The effect of the substitution program is that it is far less demanding on the cadet's time, a reduction of 24 per cent of the classroom hours over the four-year period. For each hour that the cadet is excused from ROTC classes, he is required to attend one hour of class in one of the following broad fields: General psychology; science comprehension; effective communication; and political development and political institutions. The substitute course may be a specific degree requirement during both semesters of the freshman year but should not be during the junior and senior years. The substitution during the junior and senior years should fall in the elective category.

## COURSES OFFERED IN MILITARY SCIENCE

**101. Organization of the Army.** *Prerequisite: none. (1).*

Five hours of instruction on organization of the Army and ROTC; ten hours of instruction on the M-14 rifle and marksmanship; eight two-hour periods of leadership laboratory. Academic substitution of fifteen hours (one credit hour) required. Leadership laboratory is designed to teach the fundamentals of drill, drill being the vehicle used by the ROTC for progressive leadership development and evaluation.

**102. United States Army and National Security.** *(1).*

Fifteen hours on U. S. Army and national security; seven two-hour periods of leadership laboratory. Academic substitution of fifteen hours (one credit hour) required. Leadership laboratory is designed to perfect individual performance and prepare cadets to serve as noncommissioned cadet officers during the sophomore year.

**201. Operations and Tactics.** *Prerequisite: M.S. 102. (2).*

Fifteen hours of map and aerial photograph reading; fifteen hours of introduction to operations and basic tactics; eight two-hour periods of leadership laboratory. Leadership laboratory designed to give sophomores continued opportunity to develop their leadership potential as cadet noncommissioned officers with view toward selection by army staff into advanced course.

**202. American Military History.** *Prerequisite: M.S. 102. (2).*

Twenty-nine hours of instruction on American military history; one hour of counterinsurgency operations, seven two-hour periods of leadership laboratory. Leadership laboratory designed for sophomores, acting as cadet noncommissioned officers, to develop their leadership potential teaching the freshmen.

**301. Military Teaching Principles.** *Prerequisite: M.S. 202 and selection. (1).*

Eighteen hours of instruction on military teaching principles; 45 hours (three credit hours) of academic substitution; eight two-hour periods of leadership laboratory. Leadership laboratory designed to prepare each cadet for summer camp by rotating positions of leadership (company commander, platoon lieutenant, and NCO positions) weekly within the junior class.

**302. Tactics and Communications.** *Prerequisite: M.S. 202. (3).*

Sixteen hours on leadership; nine hours on all branches of the Army; twenty-seven hours on small unit tactics and communications; three hours on precamp orientation; five hours of counterinsurgency operations; seven two-hour periods of leadership laboratory. Leadership laboratory continuation of M.S. 301.

**401. Operations, Administration, and Logistics.** *Prerequisite: M.S. 302. (3).*

Fifteen hours of instruction in operations; fifteen hours of logistics; fifteen hours of Army administration; fifteen hours of military law; two hours of map reading review; eight two-hour periods of leadership laboratory. Leadership laboratory designed for seniors to act as cadet officers by organizing, running, and evaluating the leadership laboratory for all undergraduates.

**402. Role of the United States in World Affairs.** *Prerequisite: M.S. 302. (1).*

Eight hours of instruction in the role of the United States in world affairs; five hours of service orientation; 45 hours (3 credit hours) of academic substitution; seven two-hour periods of leadership laboratory. Leadership laboratory designed as the final chance in the ROTC program for continued leadership development prior to functioning as commissioned officers on active duty in the Army.

## NAVAL SCIENCE

Professor Laforest; Associate Professor Pearson; Assistant Professors Allnutt, Dankel, Hurd, Stevens, Thorpe, and Wood; Instructors Hagar, Hepler, Keel, Mays, Morley, and Vanderhoff. Department Office, North Hall.

**Mission.** The mission of the Naval Reserve Officers Training Corps is to provide a permanent system of training and instruction in essential naval subjects at civilian educational institutions, and to provide a source from which qualified officers may be obtained for the Navy and Marine Corps and the Naval Reserve and Marine Corps Reserve.

**Objectives.** The objectives of the Department of Naval Science in carrying out the above mission at the University are:

1. To provide the student with a well-rounded course in basic naval subjects, which, in conjunction with a baccalaureate degree, will qualify him for a commission in the United States Naval Service.

2. To develop an interest in the naval service and a knowledge of naval practice.

3. By precept, example, and instruction, to develop the psychology and technique of leadership in order that the young officer may be able to inspire others to their best efforts.

4. To supplement the academic work of the school year by summer cruises, aviation training, and/or Marine Corps encampments.

5. To provide certain selected groups of students with such specific training, differentiated in the last part of the course, as will qualify them for commissions in the United States Marine Corps or the United States Navy (Supply Corps).

**Officer Candidates.** Officer candidates in the NROTC are of two types:

*a*) Regular NROTC students. These students, after selection by nationwide competitive examinations, are appointed midshipmen, USNR, and are granted a retainer pay at the rate of $600 a year, with tuition, nonrefundable fees, and books provided by the Navy for a maximum period of four years while under instruction at the NROTC institution or during summer training cruises. Regular students are obligated to serve four years on active duty after being commissioned as ensigns, United States Navy, or as second lieutenants, United States Marine Corps, unless released sooner by the Secretary of the Navy.

*b*) Contract NROTC students. The Contract NROTC students have the status of civilians who have entered into a mutual contract with the Navy. They are not entitled to compensation or benefits paid regular NROTC students except that they are entitled to the uniform issue, naval science textbooks and equipment, and payment of commutation of subsistence (currently about $30 a month) during their last two years of NROTC training. Under this plan students must agree to accept a commission in the Naval or Marine Corps Reserve on graduation, and while undergraduates, to engage in one summer practice cruise of approximately six weeks duration between the junior and senior years. After graduation, they are commissioned as ensigns, USNR, or second lieutenants, USMCR, and called to active duty for a period of obligated service. They may then apply, if they desire, for retention in the service.

Candidates must be between seventeen and twenty-one years of age. In special cases Contract students sixteen years of age may be enrolled. All must pass the Navy physical examination. Height must be between 64 and 78 inches and general physical development good. Vision must be not less than 20/40 uncorrected by glasses and in all cases must be correctible to

20/20. Candidates must be unmarried and agree to remain single until commissioned.

All students are required to complete eight semesters of naval science subjects. Candidates for Marine Corps commissions complete four semesters of general naval science subjects and four semesters of Marine Corps specialty courses. Candidates for Navy Supply Corps commissions complete four semesters of general naval science subjects and four semesters of Navy Supply Corps subjects. A psychology course taught by the civilian faculty of the University is required during one semester of the sophomore year.

Regular NROTC students participate in three summer cruises of six to eight weeks' duration; Contract NROTC students participate in one six-week summer cruise. Marine candidates spend the third cruise period at the Marine Corps Schools, Quantico, Virginia.

Contract students must have satisfactorily completed a sequence of mathematics through trigonometry in high school or one semester of mathematics in college by the end of their second year in the program. Regular students must satisfactorily complete one year of college mathematics and one year of college physics by the end of their sophomore year.

Each of the following subjects requires attendance at three one-hour recitations and a two-hour laboratory period each week.

COURSES OFFERED IN NAVAL SCIENCE

**101. Naval Orientation and Sea Power.** I. *(3).*
Study of various components of the United States Navy; shipboard organization and duties. Develops the psychology and techniques of leadership by means of practical problems and the study of the history of sea power.

**102. Naval History and Sea Power.** *Prerequisite: N.S. 101.* II. *(3).*
A study of history of sea power and its influence in shaping world affairs socially, economically, and politically.

**200. Naval Weapons.** *Prerequisite: N.S. 102.* I or II. *(3).*
A basic familiarity in modern naval weapons and the purpose of each, stressing the following specifics: ballistics and ordnance, automatic control equipment, fire control problem, and fleet air defense. Instruction in the general nature of naval weapons systems stressing guided missiles, nuclear weapons, anti-submarine warfare, and space technology. A course in psychology, as selected by the Professor of Naval Science, is required during the semester the student is not enrolled in N.S. 200.

**301. Navigation.** *Prerequisite: N.S. 200.* I. *(3).*
Thoroughly acquaints the student with the theory of dead reckoning, piloting, and celestial methods of navigation. Practical problem solution is stressed during summer cruises.

**302. Naval Operations.** *Prerequisite: N.S. 301.* II. *(3).*
Provides a broad understanding of basic naval tactics, tactical communications, relative motion, and the rules of the nautical road.

**303. Navy Supply Management.** *Prerequisite: N.S. 200.* I. *(3).*
For Navy Supply Corps candidates only. Naval finance, organization, logistics, and naval accounting methods.

**304. Navy Supply Management.** *Prerequisite: N.S. 303.* II. *(3).*
For Navy Supply Corps candidates only. Supply organization and administration afloat.

**305. Study of Evolution of Art of War.** *Prerequisite: N.S. 200.* I. *(3).*
For Marine Corps candidates only. Analysis of decisive battles of history according to principles of war and evolution of weapons.

**306. Modern Strategy and Tactics.** *Prerequisite: N.S. 305.* II. *(3).*
For Marine Corps candidates only. Study of European and United States military policies and strategies and fundamental infantry tactics.

**401. Naval Engineering.** *Prerequisite: N.S. 302.* I. *(3).*
Provides a broad general concept of the fundamentals of naval engineering installations, including steam, diesel, nuclear power, gas turbines, and auxiliary plants, and ship stability.

**402. Principles and Problems of Leadership.** *Prerequisite: N.S. 401 or 403.* II. *(3).*
Introduces the basic principles of human relations, leadership, and management with emphasis on naval shipboard administration and an introduction to the Uniform Code of Military Justice. (Required for Supply Corps students.)

**403. Navy Retail Sales.** *Prerequisite: N.S. 304.* I. *(3).*
For Navy Supply Corps candidates only. Afloat retail sales functions of the supply corps officer with emphasis on the management aspects of inventory control and merchandising.

**405. Amphibious Warfare.** *Prerequisite: N.S. 306.* I. *(3).*
For Marine Corps candidates only. The history, development, and techniques of amphibious warfare.

**406. Amphibious Warfare.** *Prerequisite: N.S. 405.* II. *(3).*
For Marine Corps candidates only. The history, development, and techniques of amphibious warfare (15 sessions only; remaining 30 sessions deal with study of naval justice and Marine Corps leadership).

# Graduate Studies

The undergraduate program in engineering offers only a limited opportunity for advanced or special studies. Many students find continued study for at least one additional year a decided advantage. It offers an attractive opportunity to pursue their special interests and to acquire a more thorough preparation for their first employment. The University of Michigan has always maintained a leading position in postgraduate engineering education and provides excellent facilities in many fields.

Opportunities to continue advanced-level study in selected engineering subjects are available in the University's graduate residence centers in the state of Michigan, provided through the Extension Service.

All students who are candidates for graduate degrees are enrolled in the Horace H. Rackham School of Graduate Studies. Its *Announcement* should be consulted for complete information.

Undergraduate students contemplating graduate work should consult with the program adviser or the advisory committee for the desired program.

## MASTER'S DEGREES

**Master of Science in Engineering.** A candidate for the degree M.S.E. —Master of Science in Engineering—must meet the requirements for the degree of Bachelor of Science in Engineering at the University in his field of specialization, or essentially the equivalent of these requirements, with sufficient evidence that he can meet the scholastic requirements of study at an advanced level.

**Master of Science.** Qualified students who have attained an undergraduate degree in an appropriate field of science are offered opportunities by the faculty of the College of Engineering in several instances to pursue their studies in selected areas that will lead to a M.S. degree—Master of Science.

**Admission Requirements.** In general, an applicant must have earned a B average in his undergraduate work to be accepted by the Horace H. Rackham School of Graduate Studies into a master's degree program. If the preparation of an otherwise acceptable candidate is not adequate, he will be required to take the necessary preparatory courses without graduate credit.

**Degree Requirement.** The requirements for a master's degree include the completion of at least thirty credit hours of graduate work approved by the program adviser or advisory committee for the program elected with an average grade of at least B covering all courses elected as a graduate student. Courses numbered 400 and above are generally acceptable for graduate credit.

A superior student who is well prepared may complete the requirements for a master's degree in two semesters.

The degrees offered are designated in the headings to the several descriptions that follow.

### M.S.E. IN AERONAUTICAL AND ASTRONAUTICAL ENGINEERING AND M.S. IN AERONAUTICS AND ASTRONAUTICS

*Advisory Committee:* Professors Adamson, Kuethe, and Willmarth; Associate Professor E. O. Gilbert.

A candidate for the M.S.E. degree will normally include in his program three to five advanced courses in aeronautical and astronautical engineering, two or three courses in mathematics beyond advanced calculus, and one or two selected courses in other cognate fields. Up to four credit hours of nontechnical studies and up to five credit hours of directed study may be elected. The courses in aeronautical and astronautical engineering may be selected to emphasize one or more of the following technical areas; gasdynamics (aerodynamics and propulsion), aerothermoelasticity, flight mechanics, guidance and control, and structures.

A candidate for the M.S. degree in aeronautics and astronautics must present substantially the equivalent of the four-year program in engineering, physics, or mathematics at the University and must complete a program of thirty credit hours to be determined in consultation with the departmental graduate committee. Normally, this program will include Physics 451 and 452, selected courses in mathematics, and several courses in aeronautical and astronautical engineering. Up to four credit hours of nontechnical studies and up to five credit hours of directed study may be elected. The courses in aeronautical and astronautical engineering may be selected to emphasize one or more of the following technical areas: gasdynamics, aerothermoelasticity, and guidance and control.

## M.S.E. IN CHEMICAL ENGINEERING

*Program Adviser:* Professor York, 3215 East Engineering Building

The requirements for the M.S.E. degree comprise a minimum of thirty hours of graduate work with a grade of B or better in each course, including Chem.-Met. Eng. 530, 541, and 542, and such other courses as are approved by the adviser. Each student is required to engage in either teaching or research activities during part of each academic year. Each student is encouraged to develop a program to fit his professional objectives and should consult with the adviser in this matter.

A full range of courses is available for those interested in many special fields, particularly: biochemical engineering, catalysis, materials, petroleum refining and production, polymers, process dynamics, process and equipment design.

## M.S.E. IN CIVIL ENGINEERING

*Program Adviser:* Professor Maugh, 301 West Engineering Building

A candidate for the M.S.E. degree must present the equivalent of the undergraduate civil engineering program as preparation and in addition must complete at least thirty credit hours of graduate work approved by the adviser, of which fifteen or more hours must be in civil engineering courses. Graduate study programs leading to this degree may be arranged in the following special areas: construction, geodetic, highway, hydraulic, hydrological, municipal, railway, sanitary, structural, soil, and transportation engineering.

## M.S.E. AND M.S. IN COMMUNICATION SCIENCES

*Advisory Committee:* Professors Burks, Fitts, Garner, Hok, Peterson, Rapoport, Thrall, and Walker; Associate Professors Galler and Swain; Assistant Professor Holland.

Candidates may be admitted to advanced study in communication sciences after a bachelor's degree in an appropriate area of concentration. See Special Fields.

They may be admitted to the M.S.E. degree program from any of the undergraduate engineering curriculums if accepted by the advisory committee. The requirements have been established in co-operation with the Department of Electrical Engineering. At least thirty hours of graduate work, as approved by the advisory committee, must be completed with an average grade of at least B for all courses elected as a graduate student.

## M.S.E. IN CONSTRUCTION ENGINEERING

*Program Adviser:* Associate Professor Harris

This program is available to students interested in construction who meet the requirements for admission to master's degree work in civil engineering. The requirements for this degree are the completion of at least thirty credit hours of graduate work including Civ. Eng. 501, 531, 532, and 545; and other courses in engineering, economics, business administration, and other fields approved by the program adviser.

## M.S.E. IN ELECTRICAL ENGINEERING

*Program Advisers:* Professors Farris, Holland, Kazda, Macnee, and Scott

A candidate for this degree must have satisfactorily completed the undergraduate electrical engineering program of the University or its equivalent. A minimum of thirty credit hours of graduate work is required for this degree and must include Elec. Eng. 620 and two courses in advanced mathematics. At least fifteen credit hours must be in electrical engineering. By suitable selection of his courses, the candidate may specialize in any of the following fields: communications engineering, computer engineering, engineering systems and design, electrical measurements and instrumentation, electric power engineering, electromagnetic field theory, control systems, energy conversion machinery, microwave engineering, physical electronics, solid-state engineering.

### M.S.E. IN ENGINEERING MATERIALS

*Graduate Adviser*: Professor Van Vlack, 4215 East Engineering Building.

A candidate for the M.S.E. degree is required to have a minimum of thirty hours of graduate credit in addition to a basic science background essentially equivalent to that represented by the program leading to the degree Bachelor of Science in Engineering (Materials Engineering) at the University, which includes chemistry, through organic and physical, structure of materials, mechanics of materials, and thermodynamics. The graduate courses are to be selected with the approval of the adviser of the program and must include at least one of the following three courses: Chem.-Met. Eng. 570, 636, or 650. Each student is required to engage in either research or teaching activities during part of each academic year.

### M.S.E. IN ENGINEERING MECHANICS

*Advisory Committee:* Professors Clark, Enns, Haythornthwaite, Masur, Ormondroyd, Smith, and Yih.

Candidates may be admitted to this degree program from any of the undergraduate engineering curriculums. A student whose undergraduate training is inadequate will be permitted to make up the deficiency in a manner prescribed by the advisory committee. The transition is simplified for those who have had some advanced mathematics.

A total of thirty credit hours of graduate study is required for the master's degree, seventeen from the graduate courses offered in the Department of Engineering Mechanics and thirteen from cognate fields. The program must include Eng. Mech. 412, 422, and 441 and Math. 552 and 555 or their equivalents. Students who have had any of the required courses, or their equivalents, may substitute cognate subjects as part of the seventeen required hours if permitted to do so by the adviser. For those who expect to pursue the doctorate, Math. 557 is recommended. A master's thesis, subject to departmental approval, may be substituted for part of the course work. The student's program of study is to be approved by the departmental graduate adviser.

### M.S.E. IN GEODETIC ENGINEERING

*Program Adviser:* Professor Berry.

This program is available to students who have satisfactorily completed an undergraduate engineering program of the University, or its equivalent, including mathematics through differential equations and at least nine semester hours in geodetic engineering. A minimum of thirty credit hours of graduate work, approved by the Department of Civil Engineering, is required for this degree, including Civ. Eng. 560 and 561; and other courses in engineering, mathematics, astronomy, city planning, or other closely allied fields related to the professional practice of geodetic engineering in government or private practice.

## M.S.E. IN INDUSTRIAL ENGINEERING AND M.S. IN INDUSTRIAL ADMINISTRATION

*Program Adviser:* Professor Hancock

A candidate for the M.S.E. degree must present substantially the equivalent of a bachelor's degree in industrial engineering at the University. He must complete in residence a minimum of thirty hours of graduate work approved by the adviser, approximately fifteen hours of this will be in the industrial engineering area.

A candidate for the M.S. dgree in industrial administration must present the equivalent of a bachelor's degree in recognized programs in any of the engineering fields, physics, or mathematics. He must complete in residence a minimum of thirty hours of graduate work approved by the adviser; approximately fifteen hours of this will be in the industrial engineering area.

## M.S.E. AND M.S. IN INSTRUMENTATION

*Program Adviser:* Professor Howe

Candidates may be admitted to the M.S.E. degree program from any of the undergraduate engineering curriculums. A minimum of thirty credit hours of graduate work is required for the degree and must include Math. 448, Elec. Eng. 438; Instr. Eng. 530, 570, 571, and Instr. Eng. 630; and other courses approved by the committee on instrumentation. The systems-engineering concept is emphasized throughout the program. See Special Fields and course listings.

For students lacking the essential equivalent of the degree Bachelor of Science in Engineering but having an acceptable science background at the bachelor's degree level, the degree Master of Science in instrumentation is offered.

## M.S.E. IN MECHANICAL ENGINEERING

*Program Adviser:* Professor Clark

The requirement for this degree is thirty credit hours of approved graduate work. At least fifteen hours must be taken in mechanical engineering and at least two cognate subjects, totaling five or more credit hours, must be taken in departments other than mechanical engineering. Details of course requirements and fields of specialization will be furnished by the department upon request.

Students majoring in mechanical engineering will not be given graduate credit for courses equivalent to any which they have been required to take for the bachelor's degree or for courses required in the undergraduate curriculum of this department.

### M.S.E. IN METALLURGICAL ENGINEERING

*Program Adviser:* Professor Hucke, 2211 East Engineering Building.

The requirements for the M.S.E. degree comprise a minimum of thirty hours of graduate work with a grade of B or better in each course, including Chem.-Met. Eng. 535, 570, and 690 (4 hours); and a minimum of one course from each of the following groups of courses: Chem.-Met. Eng. 573, 574, 587, 589; Chem.-Met. Eng. 536, 561, 577, 636; and Chem.-Met. Eng. 571, 572, 575, 870.

Other courses are to be selected as approved by the adviser. Each student is encouraged to design his program to satisfy his special interest. Each student is required to engage in either teaching or research activities during part of each academic year.

### M.S. IN METEOROLOGY AND/OR OCEANOGRAPHY

*Program Advisers:* Professors Wiin-Nielsen and Ayers.

Candidates for the M.S. in meteorology and/or oceanography must present the substantial equivalent of a bachelor's degree in engineering, physics, mathematics, or some other scientific area, including the equivalent of Math. 403 and Physics 146. Each candidate will follow a special program arranged in conference with the adviser, and the candidate may be required to make up deficiencies. A total of thirty hours is required, including fifteen hours of meteorology and/or oceanography, and six hours of mathematics, or three hours of mathematics and three hours of physical science. Interdisciplinary programs may be arranged. Six hours of course work in meteorology and/or oceanography may, after agreement with the graduate adviser, be replaced by a master's thesis.

### M.S.E. IN NAVAL ARCHITECTURE AND MARINE ENGINEERING

*Program Adviser:* Associate Professor Michelsen

A candidate for this degree must have completed the equivalent engineering courses for the degree Bachelor of Science in Engineering (Naval

Architecture and Marine Engineering) or, if he has had practical experience in the subject matter covered by these courses, pass an examination in them. The requirements usually include Math. 450, Nav. Arch. 590 or 591, Eng. Mech. 422, and electives in mathematics, engineering mechanics, and naval architecture. A total of thirty hours of graduate credit courses must be completed.

It is also possible to obtain a combined degree of Master of Science in Engineering in marine and nuclear engineering. The Graduate School requirements for such a degree are a minimum of forty hours of graduate level courses and the approval of the candidate's program by the Dean of the Graduate School.

### M.S.E. IN NUCLEAR ENGINEERING AND M.S. IN NUCLEAR SCIENCE

*Program Adviser:* Assistant Professor Gyorey

Students entering the program in nuclear engineering must have a bachelor's degree from an accredited engineering program. The nuclear science program is available to those with bachelor's degrees from recognized programs in physics, chemistry, or mathematics and who wish to work on nuclear energy development. The undergraduate preparation required for these programs is listed under Special Fields.

The credit requirements for the master's degree are thirty hours of completed course work including twenty hours from nuclear engineering. The following core courses must be included in the twenty hours: Nuc. Eng. 560, 570, 660, 670, and 680. A B average must be maintained in the core courses. All students are required to complete a one-semester research or design problem under Nuc. Eng. 690 for at least two credit hours. When desired, facilities for the supervision of work leading to a master's thesis will be made available. Additional courses are selected with the help of the program adviser from courses in nuclear engineering, cognate fields of engineering, mathematics, physics, chemistry, and others. Where the entering student presents evidence of satisfactory completion of work equivalent to any of the core courses, substitution of other courses will be arranged by the program adviser.

### M.S.E. IN PUBLIC WORKS ADMINISTRATION

*Program Adviser:* Associate Professor Glysson

The program in municipal engineering and public administration is conducted in co-operation with the Institute of Public Administration. It is available to students in the administrative problems of municipal engineering and city management who meet the requirements for admission to master's work in civil engineering.

The degree requires satisfactory completion of at least thirty hours of course work balanced between the fields of civil engineering and public administration to be recommended by the advisory committee, subject to approval of the program adviser.

### M.S.E. IN SANITARY ENGINEERING

*Program Adviser:* Professor Borchardt

The program leading to this degree is generally open to graduates in civil, chemical and mechanical engineering. A student is expected to elect at least fifteen hours of the required thirty hours for the M.S.E. degree in the field of civil and sanitary engineering. A minimum of two cognate courses is required in related fields of interest. The remainder of the program will be selected in conference with the student's adviser along lines designed to best compliment the student's ultimate objective.

## PROFESSIONAL DEGREES

Programs are offered which lead to the following professional degrees:

**Aeronautical and Astronautical Engineer**—Ae. & Astrn.E.
**Applied Mechanics Engineer**—App.M.E.
**Chemical Engineer**—Ch.E.
**Civil Engineer**—C.E.
**Electrical Engineer**—E.E.
**Industrial Engineer**—Ind.E.
**Instrumentation Engineer**—Instm.E.
**Marine Engineer**—Mar.E.
**Mechanical Engineer**—M.E.
**Metallurgical Engineer**—Met.E.
**Naval Architect**—Nav.Arch.
**Nuclear Engineer**—Nuc.E.

The professional degree programs require a minimum of thirty credit hours of work beyond the Master of Science in Engineering level or its equivalent, taken at this University with a grade average of B or better. Successful completion of a qualifying examination for admission to candidacy is required.

The total graduate program shall include:

1. At least twenty-four hours in the area of the department or program cited in the degree. The department or program advisers may specify these hours in greater detail.

2. At least six hours devoted to a research, design, or development problem, including a written report covering the work. A committee of faculty members will supervise the work, approve the report, and conduct a final oral examination on this work.

3. At least three courses in cognate fields other than mathematics.

4. At least nine hours in mathematics beyond the Bachelor of Science in Engineering mathematics requirements of the department cited in the degree.

## DOCTOR'S DEGREE

### Doctor of Philosophy—Ph.D.

The doctor's degree is conferred in recognition of marked ability and scholarship in some relatively broad field of knowledge. A part of the work consists of regularly announced graduate courses of instruction in the chosen field and in such cognate subjects as may be required by the committee. In addition, the student must pursue independent investigation in some subdivision of the selected field and must present the results of his investigation in the form of a dissertation.

A student becomes an applicant for the doctorate when he has been admitted to the Horace H. Rackham School of Graduate Studies and has been accepted in a field of specialization. No assurance is given that he may become a candidate for the doctorate until he has given evidence of superior scholarship and ability as an original investigator.

There is no general course or credit requirement for the doctorate. In most areas a student must pass a comprehensive examination in his major field of specialization, which tests his knowledge in that field and in the supporting fields, before he will be recommended for candidacy for the doctorate. A special doctoral committee is appointed for each applicant to supervise the work of the student both as to election of courses and in preparation of the dissertation.

A reading knowledge of two of the following three languages is required: German, French, or Russian. A student must meet the language requirements for the doctorate before he can be accepted as a candidate for the degree. He should consult the Examiner in Foreign Languages, 3028 Rackham Building, at his earliest convenience after becoming an applicant. A student who completes French 112, German 112, Spanish 112, or Russian 112 with a grade of B or better will be recorded as having met the language requirement in the respective language. Substitution for one of the required languages may be made under certain conditions which are defined in the *Announcement* of the Graduate School.

A pamphlet that describes the general procedure leading to the doctorate is available in the Graduate School office upon request.

# Description of Courses

The courses offered by the College of Engineering, with certain closely associated departments of other units of the University, are listed with a brief description for each.

The University year is composed of two semesters, and the credits are granted in semester hours. The present *Announcement* covers the fall and spring semesters. A special announcement is issued for the summer session. Just *prior* to the beginning of each semester and summer session a time schedule is issued giving hours and room assignments for classes.

As a general rule, courses numbered from 100 to 199 are introductory or beginning courses, 200 to 299 are intermediate, and 300 and above are advanced level courses. Those numbered 400 and above are generally acceptable for graduate credit. A Roman numeral in boldface type indicates the position of the course in a sequence of courses on the same subject. Prerequisites appear in italics immediately after course titles.

Roman numerals in lightface type indicate the semester in which the course is given: I, fall semester; II, spring semester. S.S. indicates summer session. The italic number enclosed in parentheses indicates the hours of credit for the course, e.g., *(3)* denotes three credit hours, or *(To be arranged)* denotes credit to be arranged.

## AERONAUTICAL AND ASTRONAUTICAL ENGINEERING

**200. General Aeronautics and Astronautics.** *Prerequisite: Physics 145, or equivalent.* I and II. *(2).*
Introduction to aeronautical and astronautical engineering. Elementary problems designed to orient the student in the program of aeronautical engineering, together with a discussion of the current state of aeronautical developments and the role of the engineer. Recitations and demonstrations.

**314(Eng. Mech. 314). Structural Mechanics I.** *Prerequisite: Eng. Mech. 210 or 219.* I and II. *(4).*
Review of plane states of stress and strain. Basic equations of plane elasticity and selected problems; failure criteria and applications; energy principles of structural theory; thin walled beam theory.

**320. Aerodynamics I.** *Prerequisite: preceded or accompanied by Eng. Mech. 343 and Math. 450.* I and II. *(4).*
Development of the fundamentals of aerodynamics which form the basis for the study of modern aircraft. Calculation of the forces and moments acting on wings and bodies in incompressible inviscid flow and comparison with experiment.

**330. Propulsion I.** *Prerequisite: Mech. Eng. 335, Aero. Eng. 320, or Mech. Eng. 336.* I and II. *(3).*
Introduction to aerothermodynamics and applications to problems in flight propulsion. Discussion of the momentum theorem, one-dimensional flow systems, with heat addition, shock waves, diffusers, compressors, and turbines.

**414(Eng. Mech. 414). Structural Mechanics II.** *Prerequisite: Aero. Eng. 314.* I and II. *(4).*
Introduction to plate theory. Stability of structural elements; columns and beam columns; plates in compression and shear; secondary instability of columns. Introduction to matrix methods of deformation analysis; structural dynamics. Lectures and laboratory.

**415. Principles of Structural Mechanics.** *Prerequisite: Eng. Mech. 210 or 219.* I. *(3).*
An accelerated coverage of the material in Aero. Eng. 314 and 414 designed primarily for graduate students. Not open to students who have elected Aero. Eng. 314 or 414.

**420. Aerodynamics II.** *Prerequisite: Aero. Eng. 320, and preceded or accompanied by Aero Eng. 330.* I and II. *(4).*
Continuation of Aerodynamics I. Viscous and compressible fluid theory applied to the calculation of the forces and moments on wings and bodies and comparison with experiment. Loads on an airplane. Lectures and laboratory.

**422. Theory of Propellers and Fans.** *Prerequisite: Aero. Eng. 320, and Mech. Eng. 335. (2).*
Critical study of the fundamental aerodynamic and strength theories of the propeller; viscosity and compressibility effects; theory and performance of axial and centrifugal blowers, with application to superchargers and jet propulsion systems.

**425. Principles of Aerodynamics.** *Prerequisite: Eng. Mech. 324. (3).*
An accelerated coverage of the material in Aero. Eng. 320 and 420 designed primarily for graduate students. Not open to students who have elected Aero. Eng. 320 or 420.

**430. Propulsion II.** *Prerequisite: Aero. Eng. 330 or equivalent.* I and II. *(4).*
Performance and analysis of flight-propulsion systems including the reciprocating engine-propeller, turboprop, ramjet, pulsejet, and rocket. Lectures and laboratory.

**435. Principles of Propulsion.** *Prerequisite: Mech. Eng. 335 or equivalent. (3).*
An accelerated coverage of the material in Aero. Eng. 330 and 430 designed primarily for graduate students. Not open to students who have elected Aero. Eng. 330 or 430.

**439. Aircraft Propulsion Laboratory.** *Prerequisite: preceded by Aero. Eng. 330. (2).*
Series of experiments designed to illustrate the general principles of propulsion and to introduce the student to certain experimental techniques in the study of actual propulsive devices, using full-scale or reduced models of the pulsejet, turbojet, ramjet, and rocket motors.

**441. Mechanics of Flight.** *Prerequisite: Aero. Eng. 320.* I and II. *(4).*
Mechanics of a particle applied to the analysis of vehicle flight paths. Orbits, ballistic trajectories, and trajectories of vehicles in the atmosphere. Rigid body mechanics applied to translational and rotational vehicle motion. Analysis of vehicle motion and static and dynamic stability using perturbation theory. Control characteristics.

**442. Performance of High-Speed Vehicles.** *Prerequisite: Aero. Eng. 435 and 445 or equivalent. (3).*
Properties of the atmosphere, regimes of flow, analysis and optimization of thrust programming, performance of high-speed vehicles, including coasting and glide trajectories, optimum flight paths, orbital vehicles, and re-entry problems.

**445. Principles of Mechanics of Flight.** *Prerequisite: Math. 216 or a course in differential equations. (3).*
An accelerated coverage of the material in Aero. Eng. 441 designed primarily for graduate students. Not open to students who have elected Aero. Eng. 441.

**447. Flight Testing.** *Prerequisite: Aero. Eng. 441 or equivalent. (2).*
Theory and practice of obtaining flight-test data on performance and stability of airplanes from actual flight tests. No laboratory fee will be charged, but a deposit covering student insurance and operating expense of the airplane will be required.

**449. Principles of Vertical Take-off and Landing Aircraft.** *Prerequisite: Aero. Eng. 420. (3).*
Lifting rotor and propeller analysis in vertical and forward flight; ducted fan analysis; helicopter performance analysis; transitional flight problems of VTOL aircraft; stability and control problems of helicopters and VTOL aircraft.

**460. Wind Tunnel Instrumentation.** *Prerequisite: permission of instructor. (2).*
Study of the role of schlieren, shadow, and interferometric techniques in aerodynamic research and a comparison of their relative accuracy and effect in data reduction; pressure and temperature measurements. Lectures and laboratory.

**464. High-Altitude Studies.** *Prerequisite: Math. 216 or a course in differential equations. (3).*
Upper atmosphere pressure, density, temperature, winds, composition. Rarified gas dynamics; solar constant and spectrum; the ionosphere; techniques and results of rocket research; characteristics of research vehicles; the earth satellite.

**471. Automatic Control Systems.** *Prerequisite: Aero. Eng. 441. (4).*
Transient and steady-state analysis of linear control systems; transfer functions, stability analysis, and synthesis methods; airplane transfer functions and synthesis of autopilot and powerplant control systems; use of analog computer in the laboratory for simulation. Lectures and laboratory.

**481. Airplane Design I.** *Prerequisite: Aero. Eng. 310 and 441.* I and II. *(4).*
Power-required and power-available characteristics of aircraft on a comparative basis, calculation of preliminary performance, stability, and control characteristics. Design procedure, including layouts and preliminary structural design. Subsonic and supersonic designs. Emphasis on design techniques and systems approach. Lectures and laboratory.

**482. Airplane Design II.** *Prerequisite: Aero. Eng. 480. (2).*
Design procedure, including layouts and preliminary structural design; stress analysis and detail design. Lectures and drawing.

**500. Directed Study.** *(To be arranged).*
Individual study of specialized aspects of aeronautical engineering.

**510. Structural Mechanics III.** *Prerequisite: Aero. Eng. 414.* I. *(3).*
Energy principles of structural analysis. Applications to elements of light

weight structures. Introduction to matrix force and matrix displacement methods of analysis.

**515. Structures at Elevated Temperatures.** *Prerequisite: Aero. Eng. 414 or 415. (3).*
Aerodynamic heating of high-speed aircraft and space vehicles. Thermal radiation. Heat transmission within the structure. Thermal stress; thermal deflection and buckling. Brief discussion of material properties at elevated temperature, creep, thermal stress effects on structural stiffness.

**520. Intermediate Aerodynamics.** *Prerequisite: Aero. Eng. 420 or 425 or a course in advanced calculus. (3).*
Aerodynamics of viscous and compressible fluids. Equations of motion and energy, high subsonic, transonic, and supersonic flow, shock waves, characteristics, boundary layers, turbulence, unsteady flow. Physical aspects of subject are stressed.

**521. Experimental Aerodynamics.** *Prerequisite: Aero. Eng. 520. (2).*
Covers the work presented in the experiments in Aero. Eng. 420 but with more attention to detail and more elaborate discussion of the advanced theories and methods used in this field. Lectures and laboratory.

**523. Turbulence and Diffusion.** *Prerequisite: a course in advanced calculus and Aero Eng. 420 or Eng. Mech. 324. (To be arranged).*
A physical picture of turbulence in boundary layers, wakes, jets, and behind a grid. The basic equations are derived, isotropic and locally isotropic turbulent fields are described, and applications to practical problems such as transfer and diffusion of heat and mass are treated.

**525. Aerodynamics of High-Speed Flight.** *Prerequisite: Aero. Eng. 420 or 425 or permission of instructor. (3).*
Treatment of problems in the aerodynamics of flight at supersonic and hypersonic velocities; linearized theory of wings with arbitrary planform and bodies of revolution; wing-body interference; hypersonic aerodynamics, aerodynamic heating, real gas effects.

**530. Propulsion III.** *Prerequisite: Aero. Eng. 430 or equivalent. (3).*
Continuation of Aero. Eng. 430. Further treatment of aircraft engine performance, including off-design operation, and study of selected problems in the field of propulsion.

**532. Topics in Gas Dynamics.** *Prerequisite: Aero. Eng. 420 or permission of instructor. (3).*
The role of transport phenomena in gas dynamics problems is stressed. The subjects covered include simplified gas kinetics, definition of transport properties, general conservation equations, laminar boundary layer and mixing problems with heat transfer and diffusion.

**535. Rocket Propulsion.** *Prerequisite: Aero. Eng. 430 or 435 or equivalent. (3).*
Analysis and performance of liquid and solid propellant rocket powerplants; propellant thermochemistry, heat transfer, system considerations, advanced rocket propulsion techniques.

**540. Flight Mechanics of Space Vehicles I.** *Prerequisite: Math. 216 or a course in differential equations.*
Kinematics of motion, particle dynamics, orbital motion and calculation of orbital parameters, Lagrange's equations. Rigid body dynamics including Euler's

equations, the Poinsot construction, spin stabilization, the rotation matrix. Vibrations of coupled systems, orthogonality relationships, generalized co-ordinates and system parameters.

**544. Aeroelasticity I.** *Prerequisite: Aero. Eng. 414. (3).*
Deformation characteristics of aircraft and missile structures. Deformation under dynamic loads; differential equation, integral equation, and energy methods of analysis. Nonsteady aerodynamics. Static aeroelastic effects, lifting surface flutter, and panel flutter.

**610. Structural Mechanics IV.** *Prerequisite: Aero. Eng. 510. (3).*
Matrix force, matrix displacement, transfer matrix, and finite difference methods of structural analysis. Applications to structural dynamics. Nonlinear problems in structural mechanics.

**620. Dynamics of Viscous Fluids.** *Prerequisite: Aero. Eng. 520 or permission of of instructor. (3).*
Effect of viscosity in fluid flows. Flow in laminar and turbulent, compressible and incompressible boundary layers, boundary layer stability, real gas effects at low densities.

**621. Dynamics of Compressible Fluids.** *Prerequisite: Aero. Eng. 520. (3).*
Emphasis on transonic and hypersonic flow, and on real gas effects at high temperature. Heat transfer near the stagnation point.

**622. Theory of Supersonic Wings and Bodies.** *Prerequisite: preceded or accompanied by Aero. Eng. 520. (3).*
The linearized theory of finite wings of arbitrary planform and cross section in supersonic flow. Linearized body theory, flow field around wings and bodies, interference effects. A companion course to Aero. Eng. 520 that is directed toward aerodynamic aspects of the design of supersonic aircraft and missiles.

**624. Theory of Thin Airfoils.** *Prerequisite: Aero. Eng. 320 or equivalent and preceded or accompanied by Math. 555. (3).*
Application of complex variables and mapping theory to the thin airfoil in arbitrary motion; quasi-steady theory of cambered airfoils; apparent mass and wake effects, nonstationary flow equations. Aerodynamic forces and moments are developed in a form suitable for use in the gust and flutter problems.

**626. Introduction of Magnetohydrodynamics.** *Prerequisite: permission of instructor. (3).*
Review of electrodynamics. The basic equations of magnetohydrodynamics and magnetogasdynamics, simple solutions of these equations, stability theory in laminar flow, magnetohydrodynamic shock waves, theory of characteristics, applications to aerodynamics.

**628. Molecular Theory of Flow.** *Prerequisite: Aero. Eng. 532 or permission of instructor. (3).*
Statistical mechanics approach to the subject of gas and plasma dynamics, and discussion of transition in outlook from the continuum to the kinetic viewpoint. Dynamics of rarefied neutral and ionized gases from the standpoint of Boltzmann's equation and its modified form. Topics in high-altitude aerodynamics and high-temperature flows.

**632. Combustion and Flame Propagation.** *Prerequisite: permission of instructor. (3).*
The fluid dynamic and thermodynamic relationships governing the propaga-

tion of combustion waves are derived and applied to deflagrations and detonations. Emphasis is placed on the close connection that exists between the hydrodynamics of burning mixtures and the heat release of chemical reactions.

**640. Flight Mechanics of Space Vehicles II.** *Prerequisite: preceded or accompanied by Aero. Eng. 540. (3).*
Dynamic performance of hypervelocity vehicles within the atmosphere. Problems associated with departure from and re-entry into the atmosphere.

**641. Flight Mechanics of Space Vehicles III.** *Prerequisite: Math. 450, Aero. Eng. 540, or equivalent. (3).*
Motion of a point mass in a gravitation field. Restricted three-body problems; perturbations from reference trajectories. Analysis of orbital transfers; capture and hyperbolic encounters, including error analysis. Trajectories of powered space vehicles.

**644. Aeroelasticity II.** *Prerequisite: Aero. Eng. 544. (3).*
Static and dynamic aeroelastic problems relative to swept wings and wings of low aspect ratio. Transient aeroelastic response problems. Aeroelastic effects on aircraft flying qualities.

**670. Control and Guidance of Missiles.** *Prerequisite: Instr. Eng. 670 or Elec. Eng. 646, Math. 448. (2).*
Analysis and synthesis of missile autopilot systems. Navigational homing systems; inertial and celestial navigation systems. Trajectories of ballistic missiles.

**671. Missile Guidance and Control Laboratory.** *Prerequisite: preceded or accompanied by Aero. Eng. 670. (1).*
Simulation of missile control and guidance systems on the electronic differential analyzer.

**674. Control of Space Vehicles.** *Prerequisite: Instr. Eng. 570 or equivalent and Aero. Eng. 540 or equivalent. (3).*
Analysis and synthesis of nonlinear control systems. Design of autopilots using thrust-vector control; transfer functions of elastic structures as part of closed-loop systems. Mechanization of space vehicle guidance. Attitude control of satellites and space vehicles using jet reaction and inertia wheel control systems.

**720. Physical Principles of Fluids I.** *Prerequisite: Aero. Eng. 520 or equivalent. (3).*
Physical concepts underlying the flow of fluids acted upon by stresses arising from viscosity and from electromagnetic and gravity fields. Invariant analysis of stress-strain relations. Maxwell's equations, analysis of electromagnetic stresses and energy dissipation in moving media, the equations of motion and energy in a moving fluid, and some solutions of the complete equations.

**810. Seminar in Structures.** *(To be arranged).*

**820. Seminar in Aerodynamics.** *(To be arranged).*

**830. Seminar in Propulsion.** *(To be arranged).*

**840. Seminar in Mechanics of Flight.** *(To be arranged).*

**870. Seminar in Instrumentation.** *(To be arranged).*

**880. Seminar in Space Technology.** *Prerequisite: permission of instructor. (To be arranged).*

**882. Seminar in Guided Missiles.** *Prerequisite: permission of instructor. (To be arranged).*
Primarily for military officers.

**895. Seminar in Space Research.** *Prerequisite: permission of instructor. (2).*
Detailed analysis of objectives, procedures, and results of research being carried out at The University of Michigan. Topics will include the following: structure of the upper atmosphere; measurement of temperature, pressure, density, composition, and winds. The ionosphere; measurement of ion and electron density and temperature. Investigation of radio waves incident on the earth at frequencies absorbed by the ionosphere by means of instrumented satellites. Interpretation of infrared data from meteorological satellites. Research in attitude control of multistage sounding rockets.

**900. Research.** *(To be arranged).*
Specialized individual or group problems of research or design nature supervised by a member of the staff.

## BUSINESS ADMINISTRATION*

Professors Dixon, Dykstra, Gies, Leabo, Moore, Pilcher, Rewoldt, Schmidt, and Taggart; Associate Professor Southwick; Assistant Professor Munson.

The courses listed below are of special interest to engineering students. In the election of such courses attention is called to the administrative rules of the School of Business Administration which affect elections as follows:

1. No student shall elect courses in the School of Business Administration who does not have at least third-year standing (sixty credit hours). This does not apply to Accounting 271 and 272 which are listed as sophomore-level courses in the economics department of the College of Literature, Science, and the Arts.
2. Juniors may elect courses numbered 300 to 399 inclusive, and seniors may elect any course numbered 300 to 499 inclusive, provided they have satisfied particular course prerequisites.
3. Courses numbered above 500 may be elected only by properly qualified graduate students and are not open to juniors and seniors.

For a description of courses in business administration, see the *Announcement* of the School of Business Administration. A supplement will be issued indicating the course offerings for each semester. The following are courses of particular interest to engineering students:

BUSINESS ADMINISTRATION—GENERAL

305. Business Law. *(3).*
306. Business Law. *(3).*
454. Industrial Cost Accounting. *(3).*

ACCOUNTING

271. Principles of Accounting. *(3).*
272. Principles of Accounting. *(4).*

*School of Business Administration.

FINANCE

300. Money and Banking. *(3)*.
301. Financial Principles. *(3)*.

INDUSTRIAL RELATIONS

300. Management of Personnel. *(3)*.

MANAGEMENT

311. Production Management. *(3)*.

MARKETING

300. Marketing Principles and Policies. *(3)*.

STATISTICS

300. Introduction to Statistics. *(3)*.

## CHEMICAL AND METALLURGICAL ENGINEERING

**200. Introduction to Engineering Calculations.** *Prerequisite: a university course in chemistry or physics.* I and II. *(3)*.
Material and energy balances, the equilibrium concept. Properties of fluids and solids. Engineering systems.

**230. Thermodynamics I.** *Prerequisite: Chem.-Met. Eng. 200, Math. 215, and Physics 146.* I and II. *(5)*.
Introduction to thermodynamics; mass and energy balances; use of elementary thermodynamic properties in thermochemical calculations. Generalized gas relations, charts and tables of thermodynamic properties. Includes laboratory.

**250. Principles of Engineering Materials.** *Prerequisite: Chem. 105 or equivalent; preceded or accompanied by Physics 146. (Physics 153 and Chem. 194 are equivalent to this prerequisite.)* I and II. *(3)*.
An introductory course in the science of engineering materials. Engineering properties are correlated with (1) internal structures (atomic, crystal, micro-, and macro-); and (2) service environments (mechanical, thermal, chemical, electrical, magnetic, and radiation). Two lectures and two recitations.

**270. Metals and Alloys.** *Prerequisite: Chem.-Met. Eng. 250 and Mech. Eng. 251. (3)*.
May not be elected by chemical or metallurgical engineers.
Structures and properties as affected by composition and mechanical and thermal treatment, with special emphasis on the utilization of common metals and alloys and their behavior in service. Lecture, recitation, and laboratory.

**341. Rate Processes I.** *Prerequisite: Chem.-Met. Eng. 200.* I and II. *(3)*.
A study of momentum and heat transfer and diffusion. Emphasis on measurement, interpretation, and correlation of rate data and use of rate data in design.

**342. Rate Processes II.** *Prerequisite: Chem.-Met. Eng. 230 and 341.* I and II. *(4).*
Mass transfer and chemical kinetics. Emphasis on measurement, interpretation, and correlation of rate data and use of rate data in design. Lectures, recitations, and laboratory.

**343. Separations Processes I.** *Prerequisite: Chem.-Met. Eng. 342.* I and II. *(4).*
Introduction and survey of separations based on mechanical properties, separations based on interphase activities, and capacity and performance of separations equipment. Lectures, recitations, and laboratory.

**350. Structure of Solids.** *Prerequisite: Chem. 266.* I and II. *(3).*
Atomic structure, crystallography, equilibria, rate processes, solid types, bonding, structure, imperfections. Mechanical, thermal, electrical, magnetic, optical, and surface properties of solids. Electron and zone theories of solids.

**370. Fundamentals of Casting.** *Prerequisite: preceded or accompanied by Math. 214.* II. *(3).*
Physical and chemical principles applied to casting. Experiments include mechanism and rate of solidification, flow of liquid metal, fluidity, development of residual stresses during cooling, gases in liquid metals, slag-metal reactions, operation and selection of melting furnaces.

**390. Research and Special Problems.** I, II, and S.S. *(To be arranged).*
Laboratory and/or conferences. Provides an opportunity for undergraduate students to work in research or areas of special interest such as design problems and economic studies. Where the subject covers some aspect of plant work as in summer employment in industry, arrangements should be made in advance. Not open to graduate students.

**400. Chemical Engineering Calculations.** *Prerequisite: Math. 216 or 404 and Chem.-Met. Eng. 342. (3).*
Applications of topics in mathematics to engineering problems. Solutions to ordinary and partial differential equations, orthogonality properties, matrix notations, numerical analysis.

**430. Thermodynamics II.** *Prerequisite: Chem.-Met. Eng. 230 or Sci. Eng. 330.* II. *(3).*
Basic relations among thermodynamic properties; entropy balance and concept of availability. Physical and chemical equilibrium, solutions, and equilibrium stage calculations. Elementary treatment of statistical mechanics and irreversible thermodynamics.

**439(Mech. Eng. 439). Combustion and Air Pollution Control.** *Prerequisite: permission of instructor.* II. *(3).*
Fundamentals of combustion as related to furnaces, internal combustion engines, and process plants, emphasizing formation and control of gaseous and particulate air contaminants.

**445. Applied Chemical Kinetics.** *Prerequisite: Chem. 265 and 266. (3).*
Description of kinetic systems, systematic approach to chemical reactions, mathematical and experimental characterization of kinetic systems, homogeneous and heterogeneous reactions, photochemical and chain reactions, explosions.

**446. Introduction to Control and Dynamics of Chemical Systems.** *Prerequisite: Chem.-Met. Eng. 342, 400, or equivalent. (3).*
The transient response of simple one- and two-time constant systems are considered. The relationships between electrical, thermal, mechanical, and hydraulic examples are established and defined on the basis of their frequency response

characteristics. The mathematical models for more complex chemical processing equipment and systems are derived and applied to the problems of automatic control encountered in the chemical industry.

**448. Unit Operations.** *Prerequisite: calculus, senior or graduate standing.* I. *(3).*
Equipment and theory of unit operations, including separations, heat and mass transfer with particular reference to basic operations in sanitary engineering, pharmaceutical manufacturing, and the chemical industry. Not open to chemical engineers.

**449. Fuels and Chemical Equilibrium in Combustion.** *Prerequisite: Mech. Eng. 335 or Chem.-Met. Eng. 200. (3).*
Chemical properties of jet fuels, rocket fuels, and oxidizers; computation of propulsive performance under equilibrium conditions; kinetics of reactions.

**450. Physical Ceramics.** *Prerequisite: preceded or accompanied by Chem. 266 and Chem.-Met. Eng. 350.* II. *(4).*
The nature, properties, processing, and application of ceramic materials. Lectures, recitation, and laboratory.

**451. Introduction to High Polymers.** *Prerequisite: organic chemistry, physical chemistry, or permission of instructor.* I. *(4).*
Preparation, properties, and utilization of polymeric materials. Lectures, recitation, and laboratory.

**460. Engineering Operations Laboratory.** *Prerequisite: Chem.-Met. Eng. 342.* I and II. *(3).*
Laboratory determination of operating data of equipment for chemical and metallurgical operations. Laboratory, conferences, and reports.

**470. Physical Metallurgy I.** *Prerequisite: Chem.-Met. Eng. 350.* I and II. *(4).*
Structure and properties of nonferrous metals as related to their composition, thermal and mechanical treatments. Metallurgical laboratory techniques. Lectures, recitation, and laboratory.

**471. Physical Metallurgy II.** *Prerequisite: Chem.-Met. Eng. 470.* I and II. *(3).*
Surface hardening, hardenability, hardening, tempering, isothermal transformation, related properties of iron and steel. Lectures, recitation, and laboratory.

**472. X-ray Studies of Engineering Materials.** *Prerequisite: Chem.-Met. Eng. 350 and 470.* I. *(3).*
Radiography, investigation of welds and castings; diffraction studies of metals and alloys. Lectures, recitation, and laboratory.

**477. Metallurgical Operations.** *Prerequisite: Chem.-Met. Eng. 470 or 479 or 576.* II. *(3).*
The study of deformation and joining processes and their influence on the mechanical, physical, and chemical properties of metals. Special emphasis on the roles of phase transformations, state changes, surface and stress conditions.

**479. Metals and Alloys.** *Prerequisite: Chem.-Met. Eng. 350.* I and II. *(3).*
Structures of metals as affected by composition and thermal and mechanical treatment; their resultant physical properties and behavior in service. Lectures, recitation, and laboratory.

**480. Design of Process Equipment.** *Prerequisite: preceded or accompanied by Chem.-Met. Eng. 342.* I and II. *(3).*
Applications of fluid-flow, heat transfer, mass transfer, stress analysis, and

behavior of materials to the design of chemical and petrochemical process equipment for vacuum, low-pressure, high-pressure, and high-temperature services.

**481. Chemical Process Design.** *Prerequisite: Chem.-Met. Eng. 342.* I and II. *(3).*
Application of mathematics, chemistry, and physical, natural, and engineering sciences to the design of chemical processes and engineering systems.

**484. Biochemical Technology.** *Prerequisite: Civ. Eng. 580 and organic chemistry. (3).*
Concepts necessary in the adaptation of biological and biochemical principles to industrial processes and technology of the biochemical engineering industries. Lectures, problems, and library study will be used to develop the ideas presented.

**485. Biochemical Engineering Process Design.** *Prerequisite: Chem. 222 and Chem.-Met. Eng. 342 or 448.* II. *(3).*
Selection and design of processes and equipment for the industrial manufacture of biochemicals including foods, pharmaceuticals and potable water, and for industrial waste treatment. Recitation and calculation periods.

**489. Metallurgical Process Design.** *Prerequisite: Chem.-Met. Eng. 341.* II. *(4).*
Unit process treatment of extractive metallurgical operations. Applications of principles involved in the extraction of metals from ores and scrap, the production of alloys, and their commercial shapes or forms.

**500. Advanced Chemical Engineering Calculations.** *Prerequisite: Chem.-Met. Eng. 400 and courses in differential equations and operational mathematics with concurrent registration in latter permitted.* I and II. *(3).*
Calculations on steady- and unsteady-state heat and mass transfer, stagewise operations, fluid mechanics, thermodynamics, chemical reactions, and automatic control systems. Emphasizes formulation and solution of mathematical models that are often similar for different processes.

**501. Numerical Methods in the Solution of Chemical Engineering Problems.** *Prerequisite: a course in computer programming, a course in differential equations, and a course in rate processes.* I. *(3).*
Application of numerical and computer-oriented methods to the correlation of experimental data, and the solution of problems in the fields of flow through porous media and equipment, staged operations, reaction kinetics, and heat transfer.

**510. Electrochemical Operations.** *Prerequisite: Chem.-Met. Eng. 230 and course in physical chemistry.* I or II. *(4).*
Theory and applications of electrochemistry with first half of time devoted to basic principles and last half to research problems and industrial processes. One laboratory per week included.

**521. Petroleum Engineering.** *Prerequisite: Chem.-Met. Eng. 343.* I. *(3).*
Properties of petroleum gases and liquids under pressure, process design in the production and refining of natural gas, crude oil, and other important fossil fuels.

**522. Mechanics of Multiphase Flow.** *Prerequisite: Chem.-Met. Eng. 341 or permission of instructor. (3).*
The fluid mechanics of multiphase flow systems, such as suspensions, fluidized solids, and gas-liquid systems, with emphasis on engineering principles and relation with equipment and surroundings.

**530. Thermodynamics III.** *Prerequisite: Chem.-Met. Eng. 430.* I and II. *(3).*
Statistical and irreversible thermodynamics. Equations of state; modern viewpoints. Applications to chemical engineering processes.

**535. Metallurgical Thermodynamics.** *Prerequisite: a course in physical chemistry, an undergraduate course in thermodynamics, such as Chem.-Met. Eng. 230.* I. *(3).*
Laws of thermodynamics applied to metallurgical systems. Introduction to statistical mechanics.

**536. Metal Reactions in Melting and Refining.** *Prerequisite: Chem. 469, Chem.-Met. Eng. 489.* I. *(4).*
Applied thermodynamics and kinetics of high-temperature melting and refining reactions employed in extractive metallurgical processes. Experiments concerning these reactions. Lecture and laboratory.

**541. Rate Operations I.** *Prerequisite: Chem.-Met. Eng. 342.* I. *(3).*
The first part of a unified study at graduate level of engineering operations described by rate models, including interpretation of rate data and theories and their use in process design. This part of the study stresses heat and momentum transfer.

**542. Rate Operations II.** *Prerequisite: Chem.-Met. Eng. 541.* II. *(3).*
A continuation of Chem.-Met. Eng. 541, with stress on mass transfer and chemical kinetics.

**543. Separations Operations.** *Prerequisite: Chem.-Met. Eng. 541.* II. *(3).*
Design of multicomponent separation systems including adsorption, distillation, extraction, and ion exchange. Emphasis on the concepts of the equilibrium stage and the differential contactor.

**550. Solid-State Kinetics.** *Prerequisite: physical chemistry or a course in solid state.* II. *(3).*
Kinetics and mechanics of reactions involving solids. Solid-state defects and thermodynamics and kinetics of solid-state transformations. Nonstoichiometric compounds, spinels, ceramics. Oxidation, carburization, nitridization of metals and compounds. Lectures and recitations.

**551. Solid-State Chemical Principles of Semiconductors.** *Prerequisite: Chem.-Met. Eng. 400 concurrently and a course in solid-state, or equivalent, or permission of instructor.* II. *(3).*
Structures and properties of semiconductor materials. Quantum concepts, band theory of solids. Mass action, ionization, and kinetics in semiconductors. Diffusion and field equations; p-n junction theory, Zone refining, p-n junction fabrication processes. Surface properties: adsorption and heterogeneous catalysis. Theory and materials for thermoelectric converters.

**560. Electron Microscopy.** *Prerequisite: senior or graduate standing in engineering or science.* I. *(3).*
Theory, techniques, and applications of electron microscopy. Laboratory instruction in the preparation of specimens, operation of the microscope, and interpretation of micrographs. An opportunity will be provided for laboratory work on problems of interest to individual students.

**561. Engineering Experiments and Their Design.** *Prerequisite: senior or graduate standing in engineering or science.* II. *(3).*
The use of statistical methods in analyzing and interpreting experimental data and in planning complex experimental programs. Subjects covered include: probability, distribution functions, theory of sampling techniques and process control, use of the "Chi-Square" and "t" tests in analyzing and comparing data

from simple experiments. An introduction to the analysis of variance and the design of complex experiments. Lecture, recitation, and computation.

**563. Chemical Process Control and Dynamics.** *Prerequisite: a course in Laplace transforms, or permission of instructor.* I. *(3).*
The concepts of automatic control and process dynamics are presented and applied to typical processes encountered in chemical engineering practice, such as the control of temperature, fluid-flow, mass transfer processes, and chemical reaction system.

**570. Theoretical Metallurgy.** *Prerequisite: a course in physical metallurgy.* II. *(3).*
Electron and zone theories of metals. Theories of alloying, nucleation, and growth; theories of imperfections; topology of metallurgical structures; diffusion.

**571. Physical Metallurgy III.** *Prerequisite: Chem.-Met. Eng. 471.* II. *(3).*
Ternary systems, phase transformations, plastic deformation and fracture. Lecture, recitation, and laboratory.

**572. X-ray Studies of Engineering Materials.** *Prerequisite: Chem.-Met. Eng. 472.* II. *(3).*
Application of X-ray methods to the study of age hardening, cold working, and phase changes.

**573. Corrosion and High Temperature Resistance of Metals.** *Prerequisite: Chem.-Met. Eng. 270 or 479.* I. *(3).*
Fundamentals involved in choosing a metal for use in a corroding medium or at elevated temperatures.

**574. Metals at High Temperatures.** *Prerequisite: Chem.-Met. Eng. 270, 470, or 479.* II. *(3).*
Fundamental principles determining the behavior of metals at high temperatures and the selection and performance of alloys in such applications as jet-propulsion engines, gas turbines, chemical industries, and steam power plants.

**575. Steels.** *Prerequisite: Chem.-Met. Eng. 471 or equivalent.* II. *(3).*
Theory and practice of alloy additions to steel and the effect of alloying elements on properties of steels.

**576. Metals for Process Design.** *Prerequisite: a course in physical chemistry.* II. *(3).*
The structures and properties of solids. Influence of composition, mechanical and thermal treatments on the properties of metals, and their subsequent behavior in service in industry.

**577. Metallurgical Operations.** *Prerequisite: Chem.-Met. Eng. 489.* II. *(3).*
The plastic deformation of metals and alloys. Rolling, forging, extrusion, piercing, and deep drawing.

**579. Nuclear Metallurgy.** *Prerequisite: a course in physical metallurgy.* II. *(3).*
Process, mechanical, and physical metallurgy of metals used in nuclear reactors; uranium, plutonium, and thorium. Radiation damage to solids. Container materials, fuel element design and fabrication, moderator and control elements, liquid metals.

**580(Civ. Eng. 580). Microbiology I.** *Prerequisite: Math. 216, Chem. 222, and senior standing, or permission of instructor. II. (3).*

Principles and techniques of microbiology with an introduction to their application in the several fields of engineering. Lectures and laboratory.

**581. Engineering Process Design.** *Prerequisite: Chem.-Met. Eng. 481.* I and II. *(4).*
Selection and design of processes, equipment, and control systems. Utilization and extension of minimum available information to produce workable systems. Economic studies and comparisons in optimization of systems. This course is recommended as preparation for the preliminary examination.

**582. Process Equipment Design for Advanced Chemical Engineering Students.** *Prerequisite: Chem.-Met. Eng. 343 or equivalent.* I. *(3).*
The design of chemical and petrochemical process equipment involving heat transfer and mass transfer. Process computations, stress considerations, corrosion problems and material selections, fabrication methods, assembly and maintenance problems. Equipment evaluation and estimates. Lectures, designs, and reports.

**583. Process Engineering of Polymer Plants.** *Prerequisite: Chem.-Met. Eng. 343 and 479, or permission of instructor.* II. *(3).*
Processing methods for production of polymers from raw materials. Design of plants for the manufacture of materials such as polyhydrocarbons, cellulose plastics, nylon, and rubbers.

**585. Petrochemical and Refining Studies.** II. *(4).*
Designs and economic studies of selected petrochemical and refining processes.

**586. Nuclear Fuels and Fuel Processing.** II. *(3).*
The processing of ores containing fissionable and fertile materials; the reprocessing of spent fuel systems; aqueous techniques including solvent extraction and ion exchange; pyrometallurgical methods for component separations. Problems arising when handling fissionable and radioactive materials will be treated in connection with student design problems.

**587. Cast Iron and Steel.** *Prerequisite: Chem.-Met. Eng. 270, 470, or 479.* II. *(3).*
Solidification, structures, and properties of cast ferrous metals, influence of composition, section size and other variables on the rate of malleabilization, influence of variables on the properties and structures of gray irons, selection of cast metals for specific purposes.

**589. Cast Metals in Engineering Design.** *Prerequisite: Chem.-Met. Eng. 470, 479, or permission of instructor.* II. *(3).*
An understanding of the properties of the important cast metals is obtained by melting, casting, and testing. In addition to measurement of mechanical properties, resistance to heat, wear, and corrosion is discussed. One lecture and one three-hour laboratory.

**636. Metallic-Ceramic Reactions.** *Prerequisite: physical chemistry and graduate standing.* I. *(3).*
Ceramic solids; metallic and nonmetallic liquid structures; polycomponent equilibria; polycomponent microstructures; high-temperature kinetics. Metallurgical and ceramic applications: melting and refining slags, high-temperature oxidation-reduction reactions, refractories, nonmetallic inclusions, cermets.

**640. Special Topics in Chemical Engineering.** *Prerequisite: Chem.-Met. Eng 542.* II. *(3).*
Special subjects in chemical engineering fundamentals and applications. Intensive summaries of recent research.

**645. Process Analysis.** *Prerequisite: Chem.-Met. Eng. 400 or equivalent.* II. *(3).*
Problems in the analysis, design, stability and sensitivity, optimization, and transient response of staged, continuous, and batch operations are considered with emphasis on their common mathematical and physical foundations.

**650. High Polymer Processes and Materials.** *Prerequisite: a course in physical and organic chemistry or permission of instructor.* I. *(3).*
Nature and types of polymers and copolymers. Condensation, free radical and ionic polymerization. Stereospecific polymerization. Amorphous and crystalline polymers. Structure and properties of polymeric materials, plastics, fibers, elastomers. Lectures and recitations.

**661. Design of Complex Experiments.** *Prerequisite: Chem.-Met. Eng. 561 or equivalent.* I. *(3).*
Consideration of statistical methods which are useful in designing and analyzing experiments involving several variables.

**690. Research and Special Problems.** I, II, and S.S. *(To be arranged).*
Laboratory and conferences. Provides an opportunity for individual or group work in a particular field or on a problem of special interest to the student. The program of work is arranged at the beginning of each semester by mutual agreement between the student and a member of the staff. Any problem in the field of chemical and metallurgical engineering may be selected; current elections include problems in the following fields: fluid flow, heat transfer, distillation, filtration, catalysis, petroleum, plastics, ferrous metallurgy, metals at high temperature, nonferrous metallurgy, foundry and cast metals, X-ray applications, electrodeposition, and nuclear energy. The student writes a final report on his project.

**691. Engineering Problems.** *Prerequisite: permission of instructor.* I and II. *(To be arranged).*
A study of contemporary engineering problems and of new areas of engineering exploitation of recent mathematical or scientific advances or breakthroughs.

**692. Practice of Teaching or Research.** I, II, and S.S.

**780. Advanced Separations.** *Prerequisite: Chem.-Met. Eng. 520 and 540.* I. *(3).*
Advanced study and design of multicomponent and nonideal separations with emphasis on distillation, absorption, and extraction. Equilibrium, rate and stage.

**801. Seminar in Chemical Engineering Analysis.** *Prerequisite: Chem.-Met. Eng. 500.* I. *(3).*
Modern developments in the analysis and solution of chemical engineering problems.

**830. Seminar in Engineering Thermodynamics.** *Prerequisite: Chem.-Met. Eng. 530.* I. *(3).*
Special topics in thermodynamics of chemical engineering processes. Review of latest developments and current research in thermodynamics. Students select individual problems for intensive study.

**835. Seminar in Metallurgical Thermodynamics.** *Prerequisite: a graduate course in thermodynamics.* II. *(3).*
Selected subjects in thermodynamics. Irreversible thermodynamics, and statistical mechanics applied to metallurgical systems.

**840. Heat Transfer Seminar.** *Prerequisite: Chem.-Met. Eng. 540.* I. *(2).*
Theoretical aspects of heat transfer. Classical and current developments presented by students, staff, and guest lecturers. Term paper on original work.

**841. Mass Transfer Seminar.** *Prerequisite: Chem.-Met. Eng. 540.* I. *(2).*

**845. Seminar in Applied Chemical Kinetics.** *Prerequisite: a course in chemical kinetics. (2).*

**870. Physical Metallurgy Seminar.** *Prerequisite: open to persons engaged in doctoral level research.* I. *(2).*
Selected topics in the more advanced fields of physical metallurgy.

**885. Petroleum Seminar.** *Prerequisite: Chem.-Met. Eng. 521 or 585. (2).*
Individual study of advanced topics in production, commercial natural gas, refining and petrochemical processes. Seminar and reports.

**999. Doctoral Dissertation.** I, II, and S.S. *(to be arranged).*

## CHEMISTRY*

Professor Anderson; Professors Brockway, Case, Dunn, Elderfield, Elving, Halford, Oncley, Parry, Rulfs, Smith, Tamres, Taylor, Vaughan, and Westrum; Associate Professors Ireland, Nordman, and Stiles; Assistant Professors Blinder, Cooke, Gendell, Gordus, Liu, Longone, Mark, and Martin; Instructor Lawton.

**Laboratory fees** in the range from $8 to $30 must be paid in advance for each course involving laboratory work.

**103. General and Inorganic Chemistry.** I and II. *(4).*
Elementary course for students who have not studied chemistry in high school. Three lectures, two recitations, and one three-hour laboratory.

**104. General and Inorganic Chemistry.** *Prerequisite: one year of high school chemistry.* I and II. *(4).*
Elementary course for students who have studied chemistry in high school. Three lectures, one recitation, and four hours of laboratory.

**105. General Chemistry.** *Prerequisite: Chem. 103 or 104.* II. *(4).*
Continuation of Chem. 103 or 104 for students who are not planning to take further courses in chemistry. Includes all engineering students except those planning to enter the curriculum in chemical, metallurgical, or materials engineering, who should elect Chem. 106. *Chem. 105 with a grade below B will not be accepted as a prerequisite for more advanced courses in chemistry.* Three lectures, one recitation, and three hours of laboratory.

**106. General and Inorganic Chemistry.** *Prerequisite: Chem. 103 or 104.* I and II. *(4).*
Continuation of Chem. 103 or 104 for students planning to take additional work in chemistry. Students in engineering not planning to enter the curriculum in chemical, metallurgical, or materials engineering should elect Chem. 105 rather than Chem. 106. In Chem. 103 or 104 and 106 the fundamental principles of chemistry are studied, accompanied by the descriptive chemistry of most nonmetallic elements (Chem. 103 or 104) and of the important metallic elements (Chem. 106). Three lectures, two recitations, and three hours of laboratory.

**107. General and Inorganic Chemistry.** *Prerequisite: one year of high school chemistry validated by a satisfactory grade on the placement test given during the orientation period. All other students should elect Chem. 103 or 104 followed by Chem. 105 or 106.* I. *(5).*

*College of Literature, Science, and the Arts.

Fundamental principles of chemistry and a study of the more important elements and compounds, omitting the common nonmetallic elements. Three lectures, two recitations, and four hours of laboratory.

**191. Inorganic Chemistry and Qualitative Analysis.** *Prerequisite: Chem. 104 with a grade of A or high B.* II. *(5).*
Ionic equilibrium, descriptive chemistry of the metallic elements, qualitative analysis of the metallic ions, and an introduction to thermodynamics. Three lecture-recitation periods and eight hours of laboratory.

**194. Unified Chemistry.** *Prerequisite: Physics 153.* II. *(4).*
The properties of matter discussed from the viewpoint of dynamics; discussions of thermodynamic functions, kinetic theory, and chemical kinetics. Lectures, recitations, and laboratory.

**195. Unified Chemistry.** *Prerequisite: Chem. 194.* I. *(4).*
Properties of matter from the viewpoint of atomic structure, including periodic relationships; organic and inorganic chemistry. Lectures, recitations, and laboratory.

**220. Organic Chemistry.** *Prerequisite: Chem. 106, 107, 191, or 195.* I and II. *(3).*
A survey of the field of organic chemistry. Will not meet premedical or predental requirements and is not accepted as a prerequisite for any other course in the Chemistry Department except Chem. 419 or 465. Students wishing more organic chemistry will be required to take Chem. 222 and 223.

**221. Organic Chemistry.** *Prerequisite: same as for Chem. 220. (5).*
This course is the same as Chem. 220 with the additional requirements of seven hours of laboratory for experiments which illustrate typical reactions of important types of organic compounds and standard laboratory techniques.

**222, 223. Organic Chemistry.** *Prerequisite: Chem. 106, 107, 191, or 195.* I and II. *(5 each).*
These two courses constitute a year course in organic chemistry. The first part (222) covers aliphatic compounds, carbohydrates, and other selected topics; the second part (223) covers aromatic compounds, proteins, and other topics. Students should plan programs which permit following 222 with 223 in the next semester and at the same time. Three lectures, one recitation, and two afternoons of laboratory work each week.

**265. Principles of Physical Chemistry.** *Prerequisite: Chem. 106 or 107 and preceded or accompanied by Math. 116 or 186 and Physics 145 or 153. (4).*
An introduction to topics such as: kinetic theory of gases and liquids, the first and second laws of thermodynamics, free energy and spontaneity of chemical reactions, and phase equilibrium. Lecture and recitation.

**266. Principles of Physical Chemistry.** *Prerequisite: Chem. 265 and preceded or accompanied by Math. 215 or 285 and Physics 146 or 154. (4).*
A continuation of Chem. 265 covering topics such as: chemical kinetics, electrochemistry, elementary quantum theory, and atomic and molecular structure. Lecture, recitation, and laboratory.

**346. Quantitative Analysis.** *Prerequisite: Chem. 191, 195 or 266.* I and II. *(4).*
A survey of the theory and practice of volumetric, gravimetric, electrometric, and colorimetric analysis. Systematic analysis of complex materials. Two lectures, one recitation, and two four-hour laboratory periods.

403. **Inorganic Chemistry.** *Prerequisite: Chem. 346.* I and II. *(2).*
A systematic survey of the chemistry of the elements from the standpoint of atomic structure, periodic and group relationships.

425. **Qualitative Organic Analysis.** *Prerequisite: Chem. 223 or 295.* I and II. *(3).*
Fundamental organic reactions are studied as a basis for systematic analysis and identification of organic compounds.

447. **Physicochemical Methods in Analytical Chemistry.** *Prerequisite: Chem. 346 and 468.* II. *(4).*
Theory, operation, and applicability of the principal physical and physicochemical approaches used in chemical analysis, including electrical, optical, and radiochemical methods. Lecture, recitation, and laboratory.

466. **Electrochemistry.** *Prerequisite: Chem. 469.* I. *(2).*
Elementary treatment of the fundamentals of the subject. Two lectures.

468. **Physical Chemistry.** *Prerequisite: Chem. 346, Physics 146, and Math. 214 or 215.* I and II. *(3).*
Nature of the gaseous and liquid states, solution theory, homogeneous and heterogeneous equilibria, thermochemistry and thermodynamics.

469. **Physical Chemistry.** *Prerequisite: Chem. 468.* I and II. *(3).*
Electrochemistry, atomic concepts of matter and energy, molecular and crystal structures, chemical kinetics.

481. **Physicochemical Measurements.** *Prerequisite: Chem. 346 and 468.* I and II. *(2).*
Laboratory work, including determinations of molecular weights, measurements of properties of pure liquids and solutions, and thermochemical measurements. One discussion period dealing with treatment of errors and related topics to be arranged.

482. **Physicochemical Measurements.** *Prerequisite: Chem. 481.* I and II. *(2).*
A continuation of Chem. 481. Homogeneous and heterogeneous equilibria, kinetics, atomic and molecular properties, and electrochemistry. One discussion period to be arranged.

538. **Organic Chemistry of Synthetic Polymers.** *Prerequisite: Chem. 223 or 295.* II. *(2).*
Chemistry of synthetic polymers, including the preparation of the intermediates for resins and rubber substitutes of commercial importance. Two lectures and reading.
[555. **Radiochemical Techniques.** Omitted in 1964-65.]

## CIVIL ENGINEERING

260. **Basic Surveying.** *Prerequisite: Math. 115.* I and II. *(3).*
Use, care, and adjustment of basic surveying instruments; horizontal angle measurement, leveling, taping; circular curves, grades and vertical parabolic curves, profiles, earthwork; computations, significant figures, errors, desk calculators, U.S. Public Land System.

**261. Surveying Computations.** *Prerequisite: Civ. Eng. 260 or equivalent, preceded or accompanied by Math. 116.* I and II. *(3).*
Principles of horizontal control, unified system of geometric computations based on rectangular co-ordinates and the "Intersection Solution"; logical synthesis of computations for complicated geometrical engineering applications; introduction, applications, and use of electronic computers; principles of surveying astronomy, use of ephemeris and star catalog; elements of photogrammetry.

**312. Theory of Structures.** *Prerequisite: Eng. Mech. 210.* I and II. *(3).*
Calculations of reactions, shears, and bending moments in simple, restrained, and continuous beams due to fixed and moving loads; simple trusses with fixed and moving loads; determinate frames; columns; tension members; girders; introduction to design.

**313. Elementary Design of Structures.** *Prerequisite: Civ. Eng. 312.* I and II. *(3).*
Design and details of simple beams, girders, columns, and trusses. Computations, drawing work, and laboratory experiments.

**350. Concrete Mixtures.** I and II. *(1).*
Theory and design of concrete mixtures; analysis of aggregate grading; bulking due to moisture; strength, permeability, durability, yield, and economy. Discussions, problems, and laboratory.

**362. Advanced Surveying Measurements.** *Prerequisite: Civ. Eng. 260, 261, and Math. 215.* Camp Davis. S.S. *(4).*
Precise observational methods for triangulation and control levels; use of theodolite and geodetic level, base-line measurements; electronic distance measurements; field assessment of errors and adjustments; astronomical observations for precise azimuth determinations; application of precise control to layout of engineering projects.

**363. Basic Surveying.** *Prerequisite: Math. 115 or equivalent.* I and II. *(2).*
For noncivil engineering students or those having permission of program adviser. Care, adjustment, and use of basic surveying instruments; leveling, taping, horizontal angle measurement, traverse surveys; computation, use of calculating machines.

**364. Surveying.** *Prerequisite: Math. 115 or equivalent.* II. *(3).*
Similar to Civ. Eng. 260. Designed for forestry students.

**370. Transportation Engineering.** *Prerequisite: Civ. Eng. 261.* I and II. *(3).*
Planning, location, design, construction, and maintenance of inland transportation facilities. Introduction to transportation economics.

**400. Contracts, Specifications, Professional Conduct, and Engineering-Legal Relationships.** I and II. *(2).*
Legal principles of contracts, torts, and agency; ethics, professional registration and professional conduct; technical specifications; engineering-legal relationships and problems. Lectures, reading, problems, and discussion.

**415. Reinforced Concrete.** *Prerequisite: Civ. Eng. 312.* I, II, and S.S. *(3).*
Properties of materials; stress analysis and design of reinforced concrete structures; introduction to prestressed concrete and ultimate strength analysis. Lectures, problems, and laboratory.

**420. Hydrology.** *Prerequisite: preceded or accompanied by Eng. Mech. 324 or permission of instructor.* I and II. *(3).*

The hydrograph and the various factors that affect and determine its characteristics; precipitation, evaporation, transpiration, infiltration; the unit hydrograph; the distribution graph; maximum flood flows and frequency of occurrence; normal flow and low flow; effect of forests, cultivation, and drainage; yield of wells; stream flow records. Lectures and laboratory.

421. **Hydraulics.** *Prerequisite: Eng. Mech. 324.* I and II. *(2).*
Hydrostatic stability; orifices and weirs; Venturi meters; cavitation; pump characteristics; flow in pipes and fittings, unsteady-uniform flow; steady-nonuniform flow. Lecture, laboratory, and computation.

445. **Engineering Properties of Soil.** *Prerequisite: Eng. Mech. 210 and 324.* I and II. *(3).*
Origin, evolution, and classification of soil; characteristics and properties of soil; soil moisture, ground water, capillarity, and frost action; theories of soil resistance and an introduction to practical applications including pressure distribution, bearing capacity of spread footings and pile substructures; excavations and embankment stability; highway and airport construction.

480. **Water Supply and Treatment.** *Prerequisite: Eng. Mech. 324.* I and II. *(3).*
Sources of water supply, quality and quantity requirements, design fundamentals of works for development, collection, purification, and distribution of water.

481. **Sewerage and Sewage Treatment.** *Prerequisite: Civ. Eng. 480.* I and II. *(2).*
Requirements of residential and municipal sewerage systems, procedures for the design and construction of sewerage and sewage-treatment works.

483. **Water Resources Engineering.** *Prerequisite: Eng. Mech. 324 or permission of instructor.* S.S. *(3).*
Development of water resources for purposes of supply; hydrologic factors, consideration of multiuse, water-quality parameters, distribution and treatment.

484. **Wastes Engineering.** *Prerequisite: Eng. Mech. 324 or permission of instructor.* S.S. *(3).*
Collection, treatment, and disposal of the liquid and solid wastes from urban populations.

500. **Fundamentals of Experimental Research.** I. *(2).*
The scientific method, its elements and procedures. Design of experiments, analysis of data, inferences, and conclusions; preparation for publication. Discussion, problems, and laboratory.

501. **Legal Aspects of Engineering.** I and II. *(3).*
Duty of care, nuisances, injunctions and damages, mines and minerals, carriers and shipping documents, N.L.R.A., F.L.S.A., social security, unemployment compensation, industrial injuries, and garnishment. Cases, lectures, and discussion.

505. **Boundary Surveys.** *Prerequisite: Civ. Eng. 260 or equivalent.* I. *(3).*
Problems relating to the establishment of land boundaries, including study of special legal phases which confront the land surveyor; basic principles of the U.S. Public Land System.

511. **Timber Construction.** *Prerequisite: Civ. Eng. 313.* I. *(1).*
Physical characteristics of structural woods; grading rules; design of timber structures.

**512. Advanced Theory of Structures.** *Prerequisite: Civ. Eng. 312.* I and II. *(3).*
Stresses in subdivided panel trusses; principle of virtual displacements and virtual work; energy theorems; graphical methods; analysis of statically indeterminate trusses and frames.

**513. Design of Structures.** *Prerequisite: Civ. Eng. 313 and 415.* I and II. *(3).*
Design of reinforced concrete and steel structures. Computations and drawing.

**514. Rigid Frame Structures.** *Prerequisite: preceded or accompanied by Civ. Eng. 415.* I and II. *(3).*
Analysis of rigid frames by methods of successive approximations and slope deflections; special problems in the design of continuous frames.

**515. Prestressed Reinforced Concrete.** *Prerequisite: Civ. Eng. 313 and 415.* I, II, and S.S. *(2).*
Fundamental principles of prestressing; prestress losses due to shrinkage, elastic action, plastic flow, creep, etc.; stress analysis and design of prestressed concrete structures.

**516. Advanced Design of Structures.** *Prerequisite: Civ. Eng. 513.* I. *(3).*
Functional design of buildings; selection and analysis of structural elements; reinforced concrete flat slab design; digital computer applications. Lectures and computation laboratory.

**517. Bridge Engineering and Design.** *Prerequisite: Civ. Eng. 513 or 573.* II. *(3).*
History of bridges; selection and design of reinforced concrete and steel highway and railway bridge structures based upon the requirements of economics, underclearance, site, foundations, erection, maintenance, aesthetics, safety, and financing. Lectures and computation laboratory.

**522. Hydraulic Transients.** *Prerequisite: Eng. Mech. 324.* II. *(2).*
Introduction to water-power development, including selection of type of turbine; storage and pondage; surge in pipe lines; water hammer analysis; digital programming of unsteady flow situations.

**523. Flow in Open Channels.** *Prerequisite: Civ. Eng. 421 or equivalent.* I and II. *(3).*
Laminar and turbulent flow; rapidly varied flow; subcritical and supercritical flow; transitions; channel controls; gradually varied flow translatory waves.

**524. Advanced Hydraulics.** *Prerequisite: Civ. Eng. 421.* I. *(3).*
Two-dimensional potential flow; the flow net; percolation and hydrostatic uplift; side-channel spillways; boundary-layer; hydraulic similitude; hydraulic models; stilling pools.

**526. Hydraulic Engineering Design.** *Prerequisite: Civ. Eng. 415 and 420; preceded or accompanied by Civ. Eng. 523.* II. *(3).*
Design of hydraulic structures such as diversion dams, head gates, control works, silt traps, siphon spillways, side-channel spillways, earth canals, and other structures involving accelerated flow, backwater, hydraulic jump, sedimentation, and erosion.

**531. Cost Analysis and Estimating.** I. *(2).*
Open to seniors and graduates. Elements of cost in construction; determination of unit costs; analysis of cost records; estimates of cost; amortization and debt retirement; quantity surveys.

**532. Construction Methods and Equipment.** II. *(3).*
Open to seniors and graduates. Contractors' organizations; plant selection and layout; equipment studies; methods of construction. Seminar. A student may not elect both Civ. Eng. 532 and Civ. Eng. 535 for credit to satisfy a technical option group.

**533. Estimating Practice.** *Prerequisite: preceded or accompanied by Civ. Eng. 531.* I. *(1).*
Laboratory practice in the estimating and pricing of construction work. Quantity surveys, unit costs of labor and material, indirect costs.

**534. Construction Methods and Equipment.** S.S. *(2).*
Open to seniors and graduates. Contractors' organization; plant selection and layout; equipment studies; methods of construction. (Similar to Civ. Eng. 532 but does not include seminar.)

**535. Analysis of Highway Construction Operations.** *Prerequisite: Civ. Eng. 370 and preceded or accompanied by Civ. Eng. 531 or permission of instructor.* I. *(3).*
Highway construction project planning. Analysis of construction methods and equipment productivity. Work organization and cost analysis. For use of students interested in highway construction. A student may not elect both Civ. Eng. 532 and Civ. Eng. 535 for credit to satisfy a technical option group. Lectures, recitation, and problems.

**536. Critical Path Methods in Construction.** II and S.S. *(3).*
Open to senior and graduate students. Critical path planning and scheduling, CPM and PERT programs, manpower and equipment leveling, minimum cost expediting.

**543. Soils in Highway Engineering.** *Prerequisite: Civ. Eng. 445 and 546.* II. *(2).*
Evaluation of soil in highway design and construction; soil surveys and mapping, identification and classification; subgrade bearing capacity, drainage, frost action, soil stabilization and design of flexible and rigid pavements; fills and embankments, swamp construction. Airphoto analysis; typical land forms, drainage patterns, field mapping, and materials surveys.

**544. Airport Design and Construction.** *Prerequisite: Civ. Eng. 445 and 546.* I. *(3).*
Selected problems in airport design and construction with emphasis on soil engineering; soil investigation and use of soil surveys in site selection; runway layouts, grading plans, and earthwork estimates; design and surface and subsurface drainage; airport pavement design. Airphoto analysis; typical land forms, drainage patterns, and mapping.

**545. Foundation and Underground Construction.** *Prerequisite: Civ. Eng. 445; preceded or accompanied by Civ. Eng. 546.* I and II. *(3).*
Analysis and evaluation of field borings, soil test data, and field loading tests; bearing capacity for spread footings, piles and pile groups; earth pressure and mass stability; surface excavation and embankments; tunnel construction and design; subsidence and control of damage due to subsurface excavation; investigation of overloaded foundations. Lectures, references, and design problems.

**546. Soil Mechanics Laboratory.** *Prerequisite: preceded or accompanied by Civ. Eng. 445.* I and II. *(1).*
Laboratory and field practice in soil sampling and testing, analysis and interpretation of test results; mechanical analysis. Atterberg limits, shrinkage and expansion; measurement of physical properties, direct shear, unconfined and

triaxial compression and internal stability; compaction characteristics; soil surveys and soil mapping.

**548. Marine Structures and Foundations.** *Prerequisite: Civ. Eng. 445 or permission of instructor.* I. *(2).*
Design of piers, wharves, jetties, seawalls, dry docks, and other marine structures. Energy absorbing systems, fenders, and dolphins. Waterfront construction methods including dredging, filling, cofferdams, and water control.

**550. Highway Materials.** *Prerequisite: preceded or accompanied by Civ. Eng. 370.* I. *(3).*
Sources, production, and testing of highway materials; specifications; minor research problems.

**551. Physical Properties of Concrete Masonry.** *(2).*
Design of concrete mixtures to obtain specified physical properties, including strength, elasticity, plasticity, impermeability, durability, and economy. Seminar, problems, and laboratory.

**552. Bituminous Materials and Pavements.** *Prerequisite: Civ. Eng. 370.* II. *(2).*
Selection of bituminous materials for various uses; pavement types; design of mixtures; construction and maintenance methods.

**560. Photogrammetry.** *Prerequisite: preparation in trigonometry and physics.* II. *(2).*
Basic theory of photogrammetry, geometry of photogrammetric systems, analytical solutions; application to mapping from aerial photographs.

**561. Geodesy.** *Prerequisite: Civ. Eng. 362.* I. *(3).*
Introduction to geodesy; history, theory, figure of the earth, geographic position, map projections, state plane co-ordinate systems, application to the several branches of surveying. Each student will prepare a term paper on a subject approved by the instructor. Lectures, reference work, and recitation.

**562. Geodetic Field Methods.** *Prerequisite: Civ. Eng. 561 or permission of instructor.* II. *(2).* Camp Davis S.S. *(4).*
Reconnaissance for geodetic triangulation; special observing methods for first-order horizontal and vertical control; Laplace stations and deflection of the vertical; actual observations, reduction, and adjustment of results in an actual field situation. Term paper or project report required of each student.

**563. Adjustment of Geodetic Measurements.** *Prerequisite: Math. 216 and Civ. Eng. 261 or permission of instructor. (2).*
Theory of least squares, applications to the adjustment of geodetic observations; arrangement for solution of complex adjustments on electronic computers; actual solution of selected problems.

**564. Special Problems in Advanced Surveying.** I and II. *(To be arranged).*
Special advanced work can be provided for those who have received credit in Civ. Eng. 362.

**565. Muncipal Surveying.** *Prerequisite: Civ. Eng. 362. (2).*
Control surveys, methods and adjustments for use in municipal mapping and administration, surveys for streets, utilities, property lines, tax maps, subdivision control and development.

**570. Highway Traffic.** *Prerequisite: restricted to senior and graduate students. (2).*
Characteristics of highway traffic and driver behavior, traffic control and regulation, highway safety, traffic organization and administration.

**571. Traffic Engineering.** *Prerequisite: Civ. Eng. 370 or permission of instructor.* II. *(3).*
Principles of highway traffic flow, traffic surveys and planning, analysis and presentation of data, traffic design.

**572. Highway Economics.** *Prerequisite: Civ. Eng. 370.* II. *(2).*
Principles of engineering economics applied to highway planning, location, and design; highway finance, taxation, and administration.

**573. Highway Design.** *Prerequisite: Civ. Eng. 370.* I and II. *(3).*
Studies of highway capacity, alignment, profiles, intersections, interchanges, and grade separations.

**574. Railroad Engineering.** *Prerequisite: Civ. Eng. 370.* II. *(3).*
Theory and practice of railroad engineering principles. Stresses in track, performance and durability of track materials, stabilization of ballast and roadway, maintenance of way-work equipment, organization and administration of maintenance operations.

**575. Terminal Design.** *Prerequisite: Civ. Eng. 370. (3).*
Design of railroad, highway, waterway, and airport terminals, joint terminals, layout of the various types of yards, and traffic facilities.

**576. Economics of Railroad Construction and Operation.** *Prerequisite: Civ. Eng. 370.* II. *(2).*
Statistical analysis of operating expenses. Curve, grade, and train resistances, ruling grades, rise and fall, and virtual profiles; line changes, grade reductions, and elimination of grade crossings.

**580(Chem.-Met. Eng. 580). Microbiology I.** *Prerequisite: Math. 216, Chem. 222, and senior standing, or permission of instructor.* II. *(3).*
Principles and techniques of microbiology with an introduction to their application in the several fields of engineering. Lectures and laboratory.

**581. Sanitary Chemistry.** *Prerequisite: Chem. 104 and 106 or equivalent.* I. *(2-3).*
Procedures required in the analysis of water, sewage, and industrial wastes.

**582. Sanitary Engineering Design.** *Prerequisite: Civ. Eng. 415, 480, and 481.* II. *(3).*
Computations and design of processes and typical structures related to water supply, water purification, sewerage, and sewage disposal. Drawing room and visits to plants and work under construction.

**583. Water Purification and Treatment.** *Prerequisite: Civ. Eng. 480 and 581 or permission of instructor.* II. *(3).*
Engineering methods and devices for obtaining and improving the sanitary quality and economic value of municipal water supplies; processes of sedimentation, use of coagulants, filtration, softening, iron removal, sterilization; devices and structures for accomplishing these objectives. Lectures, library reading, and visits to municipal water purification plants.

**584. Waste Water Treatment and Disposal.** *Prerequisite: Civ. Eng. 481 and 581 or permission of instructor.* I. *(3).*
Engineering, public health, legal, and economic problems involved in the design and construction of facilities for the treatment and disposal of sewage and other waste waters. Lectures, library reading, and visits to nearby disposal plants.

**585. Municipal and Industrial Sanitation.** *(3).*
Scientific foundations of public sanitation, in particular relation to closely built-up areas and to industrial environments.

**586. Industrial Waste Treatment.** *Prerequisite: Civ. Eng. 581 and 584 or permission of instructor.* II. *(2).*
Evaluation of the industrial waste problem, the character and quantity of wastes produced, and the application of engineering principles to the satisfactory disposal of these wastes.

**587. Industrial Bacteriology.** *Prerequisite: Civ. Eng. 580 or equivalent.* II. *(3).*
Lectures and demonstrations to illustrate the application of microbiological principles and techniques to industrial processes.

**602. Patent Law for Engineers.** *(3).*
Monopoly as an advancement of the arts and sciences; patentability; statutory provisions; rights of inventors generally; patent royalty contracts and assignments; procedure in preparation of patents. Texts, cases, and discussion.

**603. Public Utility Problems.** II. *(2).*
Nature of public service corporations; organization; ownership; valuation; depreciation; accounting; regulations; taxation; rates.

**611. Structural Dynamics.** *(3).*
Structural vibrations. Transient and steady-state response to dynamic forces. Response beyond the elastic range. Response to nuclear explosions. Earthquake forces. Structural response to earthquake. The response spectrum. Seismic building codes and their relation to structural dynamics.

**612. Structural Members.** I. *(4).*
Analysis and design of structural members under bending, torsion, and axial load. Beams on elastic foundations, box girders, and curved beams. Buckling of columns and beams. Emphasis on numerical methods.

**613. Structural Plate Analysis.** II. *(2).*
Stress analysis of flat plates loaded either in their plane or in bending. Numerical analysis. Applications to special problems in flat slab construction.

**614. Advanced Problems in Statically Indeterminate Structures.** *Prerequisite: Civ. Eng. 514.* II. *(3).*
Continuous truss bents; hinged and fixed arches; rings; frames with curved members; flexible members including suspension bridges; frames with semirigid connections.

**615. Analysis and Design of Folded Plates, Domes, and Shells.** *Prerequisite: Civ. Eng. 512 and 514 or equivalent.* I. *(3).*
Stresses and special design problem in folded plate construction; membrane stresses in domes and double curved shells; flexural action near boundaries; cylindrical concrete shell roofs; cylindrical tanks.

**616. Plastic Analysis and Design of Frames.** I. *(2).*
Yield, fracture, and fatigue failure of metals. Plate buckling design criteria. Rules of practice for the plastic design of structures. Plastic analysis and design of continuous beams and frames.

**617. Mechanical Methods of Stress Analysis.** *Prerequisite: preceded or accompanied by Civ. Eng. 514.* II. *(1).*

Mechanical analysis of stresses in statically indeterminate structures by means of models. Use of the Begg's apparatus in analyzing complicated structures is given particular attention. Students are required to make the models and the necessary observations and calculations.

**618. Computer Analysis of Structures.** *Prerequisite: Civ. Eng. 512 and 514.* II. *(3).*
The analysis of beams, frames, trusses, and arches by high-speed digital computer. The general method of influence coefficients; matrix methods, Algorithm development, flow charts, programming. Students will solve a sequence of problems on the high-speed computer in the University Computing Center.

**623. Applied Hydromechanics.** *Prerequisite: Civ. Eng. 523 or equivalent.* I. *(2).*
Problems in laminar flow; viscometry; the mechanics of turbulent flow; sedimentation; waves; high-velocity flow in open channels; variable flow in open channels.

**645. Theoretical Soil Mechanics I.** *Prerequisite: permission of instructor.* I. *(2).*
Stress conditions for failure in soils; arching in soils; earth pressures, retaining walls; anchored bulkheads; bearing capacity; stability of slopes; theories of elastic subgrade reaction.

**646. Theoretical Soil Mechanics II.** *Prerequisite: permission of instructor.* II. *(2).*
Effects of seepage on equilibrium of ideal soils; consolidation; mechanics of drainage; theories of semi-infinite elastic solids; behavior of soils under dynamic loads; vibrations of foundations.

**647. Soil Dynamics Laboratory.** *Prerequisite: permission of instructor.* I and II. *(1).*
Measurements of behavior of soils under static and dynamic loads; triaxial testing; evaluation of wave velocity and damping; vibrations of foundations.

**648. Dynamics of Soils and Foundations.** *Prerequisite: preceded or accompanied by Civ. Eng. 647.* II. *(2).*
Strength of soil and stability of slopes under dynamic loading; propagation of energy through soils; protective construction; excavation by explosions; compaction and settlement; vibration of foundations.

**652. Advanced Bituminous Materials and Flexible Pavement Design.** *Prerequisite: Civ. Eng. 552. (To be arranged).*
Conferences and special problems on new developments in bituminous materials, bituminous mixture design, and flexible pavement design for highways and airports. Conferences, assigned reading, laboratory investigations, and reports.

**670. Transportation Planning.** *Prerequisite: Civ. Eng. 570 and 672, or permission of instructor. (3).*
Analysis of supply and demand for transportation services, transport relationships to land use and other elements of regional and urban planning, and planning techniques applied to transportation problems.

**671. Advanced Highway Engineering.** *Prerequisite: Civ. Eng. 370.* I. *(2).*
Seminar course dealing with special phases of highway design and construction. Assigned reading and reports.

**672. Transportation.** *Prerequisite: principles of economics.* I. *(3).*
Transportation facilities, services, and policies, with emphasis on comparative performance of the various agencies of transport.

**673. Highway Transport.** II. *(2).*
Fundamentals of transportation of passengers and commodities over highways; regulation of motor carriers, management of transportation companies.

**674. Industrial Transport Management.** *Prerequisite: Civ. Eng. 672 or Econ. 433, or permission of instructor. (4).*
Analysis of industrial transportation requirements; classification, rates, and tariffs; management of private transport services; organization of traffic department; regulatory procedures and practices.

**675. Advanced Highway Design.** *Prerequisite: Civ. Eng. 573 or permission of instructor. (3).*
Comparative analysis of alternate locations and designs of urban and rural highways.

**680. Microbiology II.** *Prerequisite: Civ. Eng. 580 or equivalent. (2).*
Lectures and laboratory dealing with inter-relationships between organisms of sanitary significance such as fungi, algae, protozoa, and higher forms of invertebrates.

**681. Advanced Sanitary Chemistry.** *Prerequisite: Civ. Eng. 581.* II. *(3).*
Specialized techniques in sanitary engineering laboratory studies designed to acquaint the graduate student with modern applications of the latest analytical equipment and the fundamental principles of its operation.

**682. Advanced Sanitary Engineering Design.** *Prerequisite: Civ. Eng. 584 and preceded or accompanied by Civ. Eng. 583.* II. *(3).*
Functional design of sanitary engineering structures and typical plant layouts; drafting room and field studies; preparation of design reports.

**685. Special Problems in Sanitary Engineering I.** *(To be arranged).*
Special problems in sanitary engineering offered the first semester only. Designed to broaden the graduate student's perspective in one or more special fields.

**686. Special Problems in Sanitary Engineering II.** *(To be arranged).*
Further special problems in sanitary engineering offered the second semester only for additional special work in a limited field.

**780. Water Resource Engineering.** II. *(3).*
Conservation and protection of sources of water supply; laws governing appropriation and use of water resources as affecting both quantity and quality; standards of water quality, purposes and results of water purification; legal rights and responsibilities of public water utilities. Text and library reading, lectures, and seminar.

**810. Structural Engineering Seminar.** I and II. *(1).*
Preparation and presentation of reports covering assigned subjects.

**825. Seminar in Hydraulic Engineering.** *Prerequisite: Civ. Eng. 420 and 523. (To be arranged).*
Lectures, assigned reading, and student reports on problems selected from the field of hydraulic engineering.

**880. Sanitary Engineering Seminar.** I and II. *(1).*
Preparation and presentation of reports covering assigned topics.

**910. Structural Engineering Research.** *(To be arranged).*
Assigned work in structural engineering as approved by the professor of structural engineering. A wide range of subject matter is available, including laboratory and library studies.

**920. Hydrological Research.** *Prerequisite: Civ. Eng. 420. (To be arranged).*
Assigned work on some special problem in the field of hydrology; an enormous amount of data is available for such studies.

**921. Hydraulic Engineering Research.** *Prerequisite: Civ. Eng. 523. (To be arranged).*
Assigned work in hydraulic research; a wide range of matter and method permissible.

**930. Construction Engineering Research.** I and II. *(To be arranged).*
Selected work from a wide range of construction engineering areas including planning, equipment, methods, estimating, and costs.

**946. Soil Mechanics Research.** *(To be arranged).*
Advanced problems in soil mechanics, foundations or underground construction, selected to provide the student with knowledge of recent application and development in engineering design and construction practice. Assigned problems must be carried to a stage of completion sufficient for a written report which will normally be required for credit.

**960. Geodetic Engineering Research.** *Prerequisite: Civ. Eng. 561. (To be arranged).*
Assigned work in geodetic engineering, or other special field in surveying of interest to the student and approved by the professor of geodetic engineering.

**970. Highway Engineering Research.** *Prerequisite: permission of instructor.* I and II. *(To be arranged).*
Individually assigned work in the field of highway engineering.

**971. Transportation Engineering Research.** *Prerequisite: permission of instructor.* I and II. *(To be arranged).*
Individual research and reports on library, laboratory, or field studies in the areas of transportation and traffic engineering.

**980. Sanitary Engineering Research.** *(To be arranged).*
Assigned work upon some definite problem related to public sanitation; a wide range of both subject matter and method is available, covering field investigations, experimental in the laboratory, searches in the library and among public records, and drafting room designing.

**990. Civil Engineering Research.** I and II. *(To be arranged).*
Assigned work in the field of public utilities or engineering relations and ethics. To obtain credit, a thesis must be prepared which would be acceptable for publication.

**999. Doctoral Thesis.** I, II, and S.S. *(To be arranged).*
For doctoral candidates only, under supervision of the individual's doctoral committee.

## COMMUNICATION SCIENCES

The following courses have been developed through the co-operation of the College of Engineering and the College of Literature, Science, and the Arts, including the departments of Mathematics, Psychology, and Philosophy. These courses are offered by the graduate degree program in Communication Sciences.

**400. Foundations of the Communication Sciences.** *Prerequisite: Math. 404 and Physics 146, or permission of instructor.* I. *(3).*
Introduction to the concepts of communication and processing of information by natural and artificial systems.

**410. Communications Electronics.** *Prerequisite: Com. Sci. 400 (may be taken concurrently) and Math. 404, or permission of instructor.* I. *(3).*
Steady-state and transient analysis. Active and passive circuits. Introduction to signal analysis and to stability analysis.

**510. Signal Theory.** *Prerequisite: Com. Sci. 410 or Elec. Eng. 330, Com. Sci. 530, and Math. 425 or 465.* II. *(3).*
Further development of the mathematical tools of signal and system analysis with particular emphasis on random signals. Also the study of communication channels from the information theoretic viewpoint.

**522. Theory of Automata.** *Prerequisite: Com. Sci. 400.* II. *(3).*
Application of logic to finite computers, Turing machines, probabilistic automata, and self-reproducing automata.

**524. Theory of Adaptive Systems.** *Prerequisite: Com. Sci. 400, and Math. 473 or Elec. Eng. 465, or permission of instructor.* II. *(3).*
Theory of the design and programming of automata which change their structure and behavior in order to adapt to environments containing them.

**525. Theory of Adaptive Systems II.** *Prerequisite: Com. Sci. 524.* I. *(3).*
Continuation of Com. Sci. 524.

**541. Theory of Natural Language Structure.** *Prerequisite: Com. Sci. 400 and 410, or permission of instructor.* II. *(3).*
Introduction to physiological and acoustic phonetics and to mathematical methods in the structural description of natural language.

**560. Theory of Coding I.** *Prerequisite: Com. Sci. 400 or Elec. Eng. 465.* II. *(3).*
Finite coding theory for error checking and secrecy; linear codes, error correction capabilities of linear codes, burst error correction and codes for the checking of arithmetic, linear switching circuits, cyclic codes. Bose-Chaudhuri codes.

**573. Automatic Programming.** *Prerequisite: Math. 473.* II. *(3).*
Topics in automatic programming of digital computers, including the structure of compilers and assemblers, use of executive systems, list storage, threaded lists, and automatic programming languages.

**648. Automation of Natural Languages.** *Prerequisite: Com. Sci. 541. (3).*
Automatic speech recognition, speech synthesis, and machine translation of languages. The basic theoretical problems involved, current research literature, and current instrumental techniques in the field are studied.

**660. Theory of Coding II.** *Prerequisite: Com. Sci. 560.* II. *(3).*
Continuation of Com. Sci. 560.

**802. Interdisciplinary Seminar in Communication Sciences I.** *Prerequisite: permission of instructor.* I. *(3).*
Integration of information essential to communication sciences, and the study of theoretical formulations and experimental research in the communication sciences.

**803. Interdisciplinary Seminar in Communication Sciences II.** *Prerequisite: Com. Sci. 802.* II. *(3).*
Continuation of Com. Sci. 802.

**804. Seminar in Automata Theory.** *Prerequisite: Com. Sci. 522.* I. *(3).*

**805. Seminar in Adaptive Systems Theory.** *Prerequisite: Com. Sci. 524.* I. *(3).*

**900. Advanced Studies in the Communication Sciences.** *Prerequisite: permission of instructor.* I and II. *(1-6).*
Individual study and research.

## ECONOMICS*

Professor Smith; Professors Ackley, Basch, Boulding, Brazer, Eckstein, Ford, Haber, Katona, Lansing, Levinson, Morgan, Palmer, Peterson, Smith, Stolper, and Suits; Associate Professors G. Anderson, W. Anderson, Bornstein, Fusfield, Mueller, and Stern; Assistant Professors Aboyade, Babcock, Barlow, Chao, Morss, Parker, Pryor, Shepherd, and Teigen.

Econ. 103 and 104 are introductory courses designed especially for students in the College of Engineering and are the usual prerequisite to the election by engineering students of the more advanced courses in the Department of Economics listed below. For further details with respect to these courses and for additional courses in the field of economics, consult the *Announcement* of the College of Literature, Science, and the Arts.

*Students who elect any course without first completing the necessary prerequisites will be denied credit in that course.*

**103, 104. General Economics.** *Prerequisite: Econ. 103 is prerequisite to Econ. 104.* 103, I and II; 104, I and II. *(3 each).*
For students in the Colleges of Engineering and of Architecture and Design and other professional schools and colleges. Not open to freshmen. General survey of economic principles and problems, with primary emphasis on the latter during the spring semester.

**271, 272. Accounting.** *Prerequisite: Econ. 271 is prerequisite to Econ 272. Not open to freshmen.* 271, I and II, *(3);* 272, I and II. *(4).*
Concepts and procedure of accounting from the standpoint of investors and business management.

**401. Modern Economic Society.** I and II. *(3).*
For juniors, seniors, and graduates who have had no course in economics and who desire one semester of work in the subject. May be used as prerequisite for advanced courses with permission of course instructor. Economic principles and their application to questions of public policy.

**411, 412. Money and Banking.** *Prerequisite: Econ. 103 and 104. Econ. 411 is prerequisite to Econ. 412.* 411, I and II; 412, I and II. *(3 each).*
Nature and function of money and banking and contemporary monetary problems.

*College of Literature, Science, and the Arts.

**421, 422. Labor.** *Prerequisite: Econ. 103 and 104. Econ. 421 is prerequisite to Econ. 422.* 421, I and II; 422, I and II. *(3 each).*
Econ. 421 considers the labor force, its employment and unemployment, wages, hours, social security, and an introduction to trade unions. Econ. 422 deals with union history, union structure and organization, the development of collective bargaining, labor disputes, labor law, and the significant issues in labor relations.

**423. Social Security.** *Prerequisite: Econ. 421 or permission of instructor.* I. *(3).*
Application of the principles of social insurance to the problems of economic insecurity; unemployment compensation, old-age and survivors insurance, and health insurance; federal and state legislation and current proposals.

**431. Corporations.** *Prerequisite: Econ. 103 and 104.* I. *(3).*
Large enterprises and especially the corporate form of organization and corporation financing, with emphasis on the public interest therein and on government policies.

**433. Transportation.** *Prerequisite: Econ. 103 and 104.* II. *(3).*
An economic analysis of the transportation industries and the application of this analysis to public policy problems.

**434. Public Utilities.** *Prerequisite: Econ. 103 and 104.* II. *(3).*
Nature and problems of the public utility industries from the standpoint of government regulation.

**457. Comparative Economic Systems.** *Prerequisite: Econ. 103 and 104.* I. *(3).*
Theories of capitalism and socialism and of market and planned economies, and their application in selected countries, including the United States, the Soviet Union, and others.

**473. Fundamentals of Accounting.** *Not open to students who have had Econ. 271.* I and II. *(3).*
A survey course for those not planning further work in accounting.

**475. Economic Statistics.** *Prerequisite: Econ. 103 and 104.* I and II. *(3).*
Introduction to the principal methods of statistical analysis as applied to economic problems.

**481. Public Finance.** *Prerequisite: Econ. 103 and 104.* I. *(3).*
Principles and problems of government finance—federal, state, and local.

## ELECTRICAL ENGINEERING

**210. Circuits I.** *Prerequisite: Math. 116. (4).*
Direct-current and alternating-current circuits. Kirchhoff's laws, loop and node equations, network theorems. Alternating-current wave forms, effective and average values, instantaneous and average power. Single-phase circuits, resonance, complex operator, polyphase circuits, ideal transformers. Two lectures, one three-hour computing period, and one three-hour laboratory.

**215. Network Analysis.** *Prerequisite: preceded or accompanied by Math. 216. (3).*
Analysis of resistive, inductive, and capacitive circuits, direct current, transient and sinusoidal steady-state solution. Phasor and complex number analysis tech-

niques. Superposition and reciprocity; mesh and nodal analysis; Thevenin's and Norton's theorems; maximum power transfer. Coupled circuits and transformers; polyphase systems. Transmission lines.

**220. Electromagnetic Field Theory I.** *Prerequisite: Physics 146 and preceded or accompanied by Math. 216. (3).*

The physical and mathematical treatment of forces and energy in electrostatic fields, the capacitance and inductance of systems of conductors; the concept of polarization and magnetization; relative permittivity and permeability; Faraday's Law of Induction, Ampere's Law, and applications to simple conduction systems; Maxwell's Equations.

**301. Introduction to Systems Engineering.** *Prerequisite: preceded or accompanied by Elec. Eng. 330 or permission of instructor. (2).*

Topics in systems engineering with emphasis on generalized cost functions (dollar economics, energy availability, military values, signal perceptibility, etc.): selected applications in communication systems, electric power systems, radar systems, etc., utilizing where applicable linear analysis, probability, noise theory, computer techniques, and decision principles. Surveys of professional engineering practice with guest lecturers.

**310. Circuits II.** *Prerequisite: Elec. Eng. 210. (4).*

Writing circuit equations; node and loop methods; transient and steady-state response; Fourier series analysis; Fourier integral; transients by Laplace methods; complex frequency; poles and zeros; admittance and impedance; network theorems; graphical analysis methods; energy and power effects; polyphase circuits; electromechanical systems.

**316. Circuit Analysis and Electronics.** *Prerequisite: Math. 216 and Physics 146. (4).*

A comprehensive treatment of linear and nonlinear (electronic) circuit theory expressly developed to satisfy the requirements of nonelectrical engineering students. Laboratory experiments demonstrate and corroborate the theory developed in the class. Lectures and laboratory. Not open to electrical engineering or science engineering students.

**320. Electromagnetics and Energy Conversion.** *Prerequisite: preceded by Elec. Eng. 215, Physics 154, and Math. 216. (4).*

Discussion of the physical quantities, electrical charge, and current. Analysis of phenomena dependent on these quantities in terms of the field concept. Electric and magnetic forces; introduction to electric and magnetic properties or materials, definition of circuit elements, transient and nonlinear phenomena; magnetic circuits and principles of energy conversion. Three lectures and one three-hour laboratory.

**330. Electronics and Communications I.** *Prerequisite: Elec. Eng. 310 and 380 or Physics 455. (4).*

Circuit models of electronic devices; linear and nonlinear analysis of basic electronic circuits; rectification, amplification, modulation, and oscillation; circuit and device noise analysis. Lectures and laboratory.

**337. Electronic Circuits and Systems.** *Prerequisite: Elec. Eng. 320. (4).*

Introduction to electronic systems, block diagrams with identification of components. Analysis and design of rectifiers, amplifiers, waveform generators, and pulse circuits. Design and application of modulation and detection systems. Study of closed-loop systems including transient and steady-state response. Discussion of electronic equipment and systems, computers, control systems, and special instruments and devices. Lectures and laboratory.

**343. Energy Conversion and Control I.** *Prerequisite: Elec. Eng. 220 and 310, and Math. 404 or 450. (3).*
A unified and integrated treatment of the basic principles governing the dynamic behavior of physical components and systems utilizing field, torque, current, voltage, force, and energy relations. Application to transformers, d-c and a-c machines; hydraulic, pneumatic, photo-electrical and thermal-electric elements.

**360. Electrical Measurements.** *Prerequisite: preceded or accompanied by Elec. Eng. 310. (3).*
Methods of measuring current, resistance, electromotive force, capacitance, inductance, and hysteresis of iron, and the calibration of the instruments employed. Two lectures and one three-hour laboratory.

**361. Technical Electrical Measurements.** *Prerequisite: Elec. Eng. 360 or equivalent. (2).*
Selected topics in technical electrical measurements; dielectric measurements by Schering bridge methods, watt-hour meter calibration, magnetic measurements. One lecture and one three-hour laboratory.

**376. Electric Lighting and Distribution.** *Prerequisite: Math. 403. (2).*
For students of architecture particularly; students of electrical engineering cannot receive credit for this course.

**380. Physical Electronics of Electron Devices I.** *Prerequisite: Elec. Eng. 210 or 316; preceded by Elec. Eng. 220. (4).*
Electron tube and transistor characteristics; amplifiers, rectifiers, and equivalent circuits; electron ballistics and space-charge flow in cathode-ray and grid-controlled vacuum tubes; thermionic emission, gaseous conduction devices; energy-level diagrams for atoms, metals, and semiconductors; transistor physics. Lectures and laboratory.

**410. Circuits III.** *Prerequisite: Elec. Eng. 310. (3).*
Analysis of distributed parameter systems; transmission of electromagnetic waves in lines and waveguides; reflections; measurements; equivalent circuits; image-wave filter analysis.

**415. Network Analysis and Synthesis.** *Prerequisite: Elec. Eng. 310. (2).*
Matrix analysis of multiterminal networks; network function properties; two-port networks; synthesis of driving-point and transfer functions; cascaded networks; image filter synthesis.

**419. Transistor Circuits.** *Prerequisite: Elec. Eng. 316 or equivalent. (2).*
Not open to electrical engineering students. Basic semiconductor principles and transistor characteristics; the properties of small signal transistor amplifiers; bias considerations and temperature effects; power amplifiers, oscillators, and other circuits employing transistors; noise in transistors.

**420. Electromagnetic Field Theory II.** *Prerequisite: Elec. Eng. 220 and Math. 404 or 450. (3).*
Review of electrostatics and magnetostatics using vector calculus, solution of Laplace's and Poisson's equations in several co-ordinate systems; Maxwell's Equations, wave propagation, retarded potentials, reflection and refraction of electromagnetic radiation; applications to elementary radiating systems. Antennas.

**430. Electronics and Communications II.** *Prerequisite: Math. 404 or 450 and Elec. Eng. 330. (3 or 4).*

Basic concepts of information theory; signal transmission through electric networks; amplitude, frequency, and pulse modulation with system concepts; noise in electronic devices and circuits; statistical methods in analyzing information transmission systems. Three credit hours without laboratory.

**433. Electroacoustics and Ultrasonics.** *Prerequisite: Math. 404 or 450 and Elec. Eng. 310, or permission of instructor. (3).*
Derivation of the equations for propagation of sound; electromechanical and electroacoustical systems in terms of equivalent electrical networks; loudspeakers and microphones; acoustic instrumentation and measurements. Lectures and laboratory.

**434. Architectural Acoustics.** *Prerequisite: Math. 116 or permission of instructor. (2).*
The application of acoustics to architectural problems. Acoustical terminology and the properties of sound waves. Sound absorptive materials, noise control in relation to architecture, and the acoustics of rooms and buildings.

**438. Electronics and Radio Communications.** *Prerequisite: Elec. Eng. 310 or 316 or permission of instructor. (4).*
Electron tubes and semiconductors as circuit elements; network theory including these elements; amplifiers, radio-frequency circuits. Amplitude, frequency and pulse modulation, frequency spectra. Radio receivers and transmitters, noise in communication circuits. Not open to electrical engineering students. Lectures and laboratory.

**440. Direct- and Alternating-Current Machines.** *Prerequisite: preceded or accompanied by Elec. Eng. 316. (1).*
Theory and application of direct- and alternating-current rotating equipment. One three-hour lecture-laboratory period per week. May be substituted for the laboratory part of Elec. Eng. 316 except by students required to or planning on taking Elec. Eng. 442.

**442. Automatic Control, Electronics, and Electromechanical Energy Conversion.** *Prerequisite: Elec. Eng. 316. (4).*
Principles of automatic control, stability, steady-state and transient response; analysis of electronic systems; electromechanical energy conversion, alternating-current and direct-current machine applications; control-system design; three lectures and one four-hour laboratory. Not open to electrical engineering students.

**444. Energy Conversion and Control II.** *Prerequisite: Elec. Eng. 343 or permission of instructor. (4).*
Generalization of the basic principles of the dynamic behavior and energy conversion of physical elements, including an introduction of Lagrange's equations, Hamiltonian functions, and Legrendre transformations. Introduction to feedback control-system principles and transfer functions. Laboratory experiments demonstrating and corroborating the theory developed in class. Lectures and laboratory.

**465. Electronic Computers I.** *Prerequisite: Math. 404 or 450, preceded or accompanied by Math. 273. (4).*
Introduction to the design and engineering application of digital computers, differential analyzers, and digital-differential analyzers. Treats computer organization and languages; system modeling and simulation; elementary numerical analysis; application of computers to engineering problems. Lectures and laboratory.

**466. Digital-Computer Engineering Laboratory.** *Prerequisite: Elec. Eng. 465 or permission of instructor. (2).*
Study of logic circuits and electronic circuits of digital-computer systems. Laboratory projects are carried out on the MIC (Michigan Instructional Computer) to investigate circuits for arithmetic, control, and storage. Lecture and laboratory.

**467. Switching Circuits and Logical Design.** *Prerequisite: junior standing in engineering. (3).*
Introduction to methods of designing and minimizing networks of switching elements, such as relays, magnetic cores, transistors, or other computer elements. Use of switching algebra and graphical techniques for the logical design of combinational and sequential switching circuits.

**470. Fundamentals of Electrical Design.** *Prerequisite: Elec. Eng. 210 and 220. (4).*
Design problems from various types of apparatus involving the electric and magnetic circuits; field mapping, heat-transfer and temperature-rise work. Three lectures and one four-hour computing period.

**473. Analysis and Design Projects.** *Prerequisite: senior standing in engineering.* II. *(4).*
Professional problem-solving methods developed through intensive group and individual studies of two or three significant engineering devices; use of analytic, computer, and experimental techniques where applicable. Two lectures and two project periods.

**475. Optics of Coherent and Noncoherent Electromagnetic Radiations.** *Prerequisite: preceded or accompanied by Math. 450 and Elec. Eng. 420 or permission of instructor. (3).*
Review of the properties of light and of basic geometrical and physical optics; operational Fourier-transform and matrix treatment of optical image-forming processes, diffraction, spectroscopy and communications; optical filtering and computing; relativistic, statistical, and coherence properties of light; coherent light generation, amplification and control with optical masers; wave-propagation, frequency multiplication, and shifts in nonlinear media. Similarities and relations with microwave and electronic systems techniques.

**477. Residence Lighting.** *Prerequisite: preceded by Elec. Eng. 376 or 475. (2).*
For students of architecture and engineering. Co-ordination of architecture with illumination as applied to residence lighting.

**499. Directed Research Problems.** *Prerequisite: Elec. Eng. 210. (To be arranged).*
Special problems are selected for laboratory or library investigation with the intent of developing initiative and resourcefulness. The work differs from that offered in Elec. Eng. 699 in that the instructor is in close touch with the work of the student. Elec. Eng. 699 is for graduates.

**510. Transients.** *Prerequisite: Elec. Eng. 310. (2).*
Advanced theory of electrical circuits; Laplace transform method of solution for transients in circuits with lumped constants; introduction to the complex frequency domain.

**515. Network Synthesis I.** *Prerequisite: Elec. Eng. 415 or 510, or permission of instructor. (3).*
Energy relations in passive networks; complex variable theory; realizability and synthesis of driving-point impedance and transfer functions.

**523. Application of Acoustics to Engineering Problems.** *Prerequisite: Elec. Eng. 433 or senior standing with permission of instructor. (2).*

Fundamental and practical acoustics involved in product design, development, and quality-control. Acoustic fields source and boundary characteristics, applications to anechoic and reverberant chambers. Types of acoustic measurements possible, valid deductions about noise sources from practical measurements. Maintenance of acoustic calibrations and acoustic criteria. Lectures and demonstrations.

**526. Electric and Magnetic Properties of Solids I.** *Prerequisite: Elec. Eng. 420 or permission of instructor. (3).*

The role of solids in determining the electric and magnetic parameters both of circuit elements and of wave propagation; thermodynamics of electric and magnetic processes; thermoelectric transport equations; development of Schroedinger's Equation and its application to the hydrogen atom, the periodic table; binding and conduction processes in solids.

**530. Microwaves I.** *Prerequisite: Elec. Eng. 410 and 420. (4).*

Theory and practice of microwave techniques; microwave generation, detection, and measurement; electromagnetic waves; wave guides and cavity resonance phenomena; special circuits. Lectures and laboratory.

**531. Radiation, Propagation, and Antennas.** *Prerequisite: Elec. Eng. 330, 410, and 420. (3).*

Fundamental theory; linear antennas and arrays in free space and in proximity to the earth; effective aperture and gain; basic transmission loss; ground-wave propagation; the ionosphere and sky-wave propagation; tropospheric propagation; ionosphere and tropospheric scatter.

**533. Pulse Circuits.** *Prerequisite: Elec. Eng. 330. (3).*

Waveform generation multivibrators, sawtooth generators, ringing oscillators, regenerative circuits, pulse-forming lines; pulse amplifier design; overshoot, sag, and applied transient analysis of linear amplifiers; use of maximally flat, linear phase, equal ripple, and other amplifier functions. Lectures and demonstrations.

**534. Noise in Electronic Circuits and Devices.** *Prerequisite: Elec. Eng. 310, Math. 404 or 450, and preceded or accompanied by Math. 552, or permission of instructor. (3).*

Probability and random processes; extension of Fourier analysis; sampling in the time domain; entropy of a random process; properties of a noise process; response of linear and nonlinear circuits to noise; noise factor; sources of noise in electronic circuits and devices.

**535(Astron. 535). Astronomical Radiophysics.** *Prerequisite: Elec. Eng. 420 or permission of instructor.* II. *(3).*

Review of electromagnetic theory. Propagation of radio waves through ionized media. Radiation by elementary dipoles and accelerated charges; emission and absorption in ionized media including thermal, Cerenkov, and synchrotron mechanisms. The emphasis is on astronomical rather than engineering applications.

**536(Astron. 536). Introduction to Radio Astronomy.** *Prerequisite: Elec. Eng. 535 or permission of instructor.* I. *(3).*

The fundamental definitions and basic concepts necessary for a study of space and ground-based radio astronomy. The basic observational techniques, radiometer system designs, antenna problems, and data analysis methods. The observational results and the theory of radio emission from celestial bodies will be treated.

**539. Electronic Circuit Design.** *Prerequisite: Math. 404 or 450, Elec. Eng. 330, or permission of the instructor.* II. *(3).*

Topics to be drawn from the areas of: low noise circuits, oscillator design, parametric amplifiers and converters, tunnel diode circuits, integrated circuits, feedback amplifiers, modulation circuits, active circuit synthesis. Two lectures and one laboratory period a week.

**541. Alternating-Current Apparatus.** *Prerequisite: Elec. Eng. 444. (3).*

Advanced treatment of coupled circuits as applied to transformers and the induction machine. Generalized four terminal network theory and generalized circle diagrams. Space m.m.f. harmonics, rotating m.m.f. components, and harmonic iron losses of polyphase and single-phase windings.

**542. Synchronous Machinery.** *Prerequisite: Elec. Eng. 444. (2).*

M.m.f. and flux distribution in the air gap and voltage wave shapes of non-salient and salient pole machines. Direct and quadrature reactances under steady-state and transient conditions.

**545. Linear Control-System Theory I.** *Prerequisite: Math. 404 or 450 and Elec. Eng. 444 or permission of instructor. (2).*

A theoretical study of feedback control systems; transfer function analysis; stability considerations; system sensitivities; root locus and frequency response techniques; introduction to discrete-time systems.

**547. Control-System Design.** *Prerequisite: Elec. Eng. 545 or Instr. Eng. 570 or permission of instructor. (4).*

Application of linear control-system theory to the design of complex systems. Emphasis is placed on the following topics; major design choices required, performance criteria, system compensation, linear syntheses techniques. Laboratory experiments involve the study of several control systems and their simulation on the analog computer. Lectures and laboratory.

**549. Foundations of Control Systems Engineering.** *Prerequisite: Elec. Eng. 301, 545, or permission of instructor.* II. *(3).*

An introduction to the analysis of dynamic control systems utilizing the concepts of sets, function spaces, and linear operators to analyze continuous, discrete, and distributive control systems. Emphasis is placed on state-space concepts including transition matrices, canonical system forms, and mode analysis.

**552. Electric Rates and Cost Analysis.** *Prerequisite: permission of instructor. (1).*

Capitalization; fair return on investments; analysis of costs and value of electrical energy; customer charge, demand charges, energy charges; investigations of practical systems used in charging for electrical energy.

**553. Power Systems Analysis I.** *Prerequisite: Elec. Eng. 410. (3).*

Energy sources; transmission line constants; generalized circuit constants; circle diagrams; transmission line-loss formulas; load dispatching; tap changing and phase shifting transformers. Problem solving on the network computer.

**554. Computer Applications in Power Systems I.** *Prerequisite: preceded or accompanied by Elec. Eng. 553. (2).*

Application of the digital computer to problems in network reduction, power-plant performance, system losses, and economic loading of alternators. On-line and off-line dispatch computers. Problem solving on the digital computer.

**557. Power System Protection.** *Prerequisite: permission of instructor. (2).*
Theory of overcurrent, differential, distance, pilot wire and carrier current relaying systems and their application for the protection of power systems. System grounding and the ground fault neutralizer.

**558. Power System Transients.** *Prerequisite: permission of instructor. (2).*
Lightning and its effects on a power system. Insulation and design for integrated protection. Transients due to lightning and system switching. Attenuation and reflection of traveling waves. Ground wires, counterpoise, and application of lightning arresters.

**559. Power Systems Laboratory.** *Prerequisite: permission of instructor. (1-3).*
Facilities available for laboratory studies in power systems. Graduate students electing this course, while working under the general supervision of a member of the staff, are expected to plan and carry out the work themselves and to make reports in the form of theses.

**560(Com. Sci. 560). Theory of Coding I.** *Prerequisite: Elec. Eng. 465 or Com. Sci. 400.* II. *(3).*
Finite coding theory for error checking and secrecy; linear codes, error correction capabilities of linear codes, burst error correction and codes for the checking of arithmetic, linear-switching circuits; cyclic codes. Bose-Chaudhuri Codes.

**565. Electronic Computers II.** *Prerequisite: Elec. Eng. 465 or permission of instructor. (3).*
Logical structure of computers; methods of problem preparation and scope of problems; study of computer components such as integrating amplifiers, magnetic and electrostatic storage elements, input and output devices. Lectures, laboratory work on department computers, and demonstrations of University computing facilities.

**568. Digital-Computer Applications.** *Prerequisite: Elec. Eng. 438 and Math. 448. (3).*
Logical structure and organization of digital computers; number systems, flow diagrams, and problem preparation; special topics in digital-computer applications to simulation and system study. Lectures and laboratory work on the University computing facilities.

**570. Heat Problems in Electrical Design.** *Prerequisite: permission of instructor. (2).*
Advanced work in the fundamentals of heat transfer by radiation, conduction, and natural and forced convection; application to specific situations.

**577. Interior Illumination, Study of Design.** *Prerequisite: Elec. Eng. 475 or equivalent. (2).*
Unusual as well as typical designs of lighting, particularly those which have been actually built and are available for testing as a check upon the calculations, are analyzed quantitatively and qualitatively.

**580. Physical Electronics of Electron Devices II.** *Prerequisite: Elec. Eng. 380, or permission of instructor. (4).*
Conformal analysis of fields in space-charge control tubes; multigrid-tube interelectrode capacities; electron transit-time principles; electron optics of cathode-ray focusing; solid-state physics of thermionic, secondary, and photo-electric

emission; mobilities, mean-free times, and conductivities in semiconductors and in gaseous conducting plasmas; television pickup and camera tubes; initiation of current in thyratrons, ignitrons, and circuit breakers; Paschen's Law, radiation counter tubes. Lectures and laboratory.

**588. Theory of Solid-State Electronic Devices.** *Prerequisite: Elec. Eng. 380 and Math. 404 or 450. (3).*

Structure of solids, metals, ionic crystals, and valence crystals. Band theory of solids. Electron energy distribution; Fermi level, mean-free time, life and mobility of holes and electrons. Junctions; rectifiers, thermistors, transistors, and photoconductive cells. Ferromagnetism, ferroelectricity, and piezoelectricity. Domain structure; reversible and irreversible movements of domain walls. Metals, alloys, ferrospinels, barium titanate.

**591. High-Voltage Experimental Techniques.** *Prerequisite: Elec. Eng. 310 and 380. (1).*

Cathode-ray oscilloscope measurements of fast transient voltages such as occur on electric utility power lines, in automobile ignition systems, and in radar modulators; circuit breaker principles; surge generators; lightning arresters; insulation and corona problems. One four-hour laboratory.

**592. Electron Tube and Vacuum Techniques.** *Prerequisite: Elec. Eng. 380 and permission of instructor. (1).*

Laboratory exercises and the techniques employed in vacuum-tube research and engineering and in physical electronics. One four-hour laboratory.

**615. Network Synthesis II.** *Prerequisite: Elec. Eng. 515. (3).*

Synthesis for prescribed transfer functions; the approximation problem; synthesis for a prescribed time response; application to engineering problems.

**617. Network Analysis.** *Prerequisite: Elec. Eng. 510 or 515, or permission of instructor. (3).*

Stability theory and feedback amplifier design, and selected topics from the following: Hilbert transforms, band-pass analysis, Z-transforms, correlation and spectral analysis, and radar and communication-systems analysis by circuit theory concepts.

**620. Electromagnetic Field Theory III.** *Prerequisite: Elec. Eng. 420 and Math. 450. (3).*

Review of electrostatics from an advanced viewpoint; multipole fields, Green's functions, electric and magnetic energies, volume forces, and stress tensors in material media; Maxwell's Equations, inhomogeneous vector-wave equation. Hansen's Method, Hertz potentials, radiation and scattering. Fields of point charges in uniform motion and accelerated charges.

**626. Electric and Magnetic Properties of Solids II.** *Prerequisite: Elec. Eng. 526 or permission of instructor. (3).*

Electronic processes within periodic potential fields. The origin and frequency dependence of permittivity and permeability. Metallic conduction, superconductivity and superconductive devices. Ferromagnetism and microwave ferrimagnetic devices.

**630. Microwaves II.** *Prerequisite: Elec. Eng. 530 or permission of instructor. (3).*

General field theory for wave guides; the impedance concept and the application of network theory to microwave structures, general network theorems; analytical methods for determining equivalent circuits for microwave structures, the integral equation formulation. Green's function, variational techniques, and applications to typical boundary value problems; propagation in anisotropic media, nonreciprocal devices; the scattering matrix, and the analysis of multiport networks.

**634. Information Theory in Electrical Communication.** *Prerequisite: Elec. Eng. 534 or equivalent preparation in probability and statistics. (3).*
Communication signals as random processes. Power spectra and correlation functions of various signals; entropy as a measure of information; optimum prediction and filtering; statistical inference applied to detection of signals in noise; components of communication channel; theoretical capacity of discrete and continuous channels; systems for encoding information into signals. Evaluation of amplitude, frequency and pulse modulation systems for transmission of information.

**645. Linear Control-System Theory II.** *Prerequisite: Elec. Eng. 545 or Instr. Eng. 570 or permission of instructor. (3).*
Time-varying linear systems; time-domain synthesis; stochastic processes in control systems; optimal systems; discrete-time systems.

**646. Nonlinear Control-System Theory.** *Prerequisite: Elec. Eng. 545 or Instr. Eng. 570 or permission of instructor. (3).*
Analysis and design nonlinear systems; describing function techniques; approximation methods; phase- and state-space methods; stability concepts; optimal systems; introduction to Lyapunov's Second Method.

**647. Introduction to Navigation Systems.** *Prerequisite: Elec. Eng. 545 or Instr-Eng. 570 or permission of instructor. (2).*
A theoretical study of the basic concepts which underlie celestial, Doppler, and inertial navigation systems; vehicle reference co-ordinate systems; Schuler tuning; hybrid systems; theory and application of gyroscopes, accelerometers, and astrocompasses as applied to navigation systems.

**653. Power Systems Analysis II.** *Prerequisite: Elec. Eng. 553. (3).*
Symmetrical and alpha, beta, zero components; alternator impedances; balanced and unbalanced faults; steady-state and transient stability. Problem solving on network computer.

**654. Computer Applications in Power Systems II.** *Prerequisite: preceded or accompanied by Elec. Eng. 653. (2).*
Application of the digital computer in the determination of load flow, transient stability, and fault conditions in a power network. Problem solving on the digital computer.

**660(Com. Sci. 660). Theory of Coding II.** *Prerequisite: Elec. Eng. 560 (Com. Sci. 560). (3).*
Continuation of Elec. Eng. 560. Finite arithmetic code theorems, finite arithmetic codes and machine arithmetic, unit distance codes, error correcting and detection properties of arithmetic codes.

**665. Digital-Computer Design Principles.** *Prerequisite: Elec. Eng. 565. (3).*
Study of the logic of series and parallel type computers; logic circuits for computation and control; characteristics of pulse circuits, memory elements, and input-output system.

**667. Theory of Networks of Switching Elements.** *Prerequisite: Elec. Eng. 467, Philos. 414, or permission of instructor. (3).*
The use of Boolean algebra and propositional calculus in the study of two-

terminal and multiterminal relay contact networks; analysis and synthesis of sequential networks and functional automata; use of predicate calculi in the theory of logical design; other current topics. The point of view is that of abstract algebra.

**673. Large Scale Systems Theory and Design.** *Prerequisite: Elec. Eng. 534 or permission of instructor. (3).*
Criteria, optimization, and synthesis methods appropriate to engineering systems. Topics may include: system representation, statistical analysis and synthesis, utilization of nonlinear techniques, modeling of specific engineering systems.

**686. Microwave Electron-Beam Tubes I.** *Prerequisite: Elec. Eng. 620 or permission of instructor. May be elected for 2 hours credit without laboratory with permission of instructor. (3).*
Llewellyn-Peterson analysis; general induced-current theory; electron optics of low-density and high-density beams, conservation of momentum, Busch's theorem, confined flow, Brillouin flow, Harris flow, electrolytic tanks; space-charge wave analysis; velocity modulation, klystrons, small-signal traveling-wave tubes, magnetron amplifiers, backward-wave oscillators, double-beam tubes. Lectures and laboratory.

**687. Microwave Electron-Beam Tubes II.** *Prerequisite: Elec. Eng. 686 or permission of instructor. (3).*
Electric and magnetic lenses, periodic magnetic focusing, effect of magnetic field on space-charge wave propagation; nonlinear theory of O-type amplifiers and oscillators; nonlinear theory of M-type amplifiers and oscillators; space-charge models; omega-beta diagram, periodically loaded waveguides.

**689. Noise in Electron-Stream Devices.** *Prerequisite: Elec. Eng. 534, 620 and 686, or permission of instructor. (2).*
Statistical mechanics of multi-electron systems; medium-like models of an electron gas, applied to electron beams, gas discharges and solids; single-velocity and Maxwellian streams; generation and propagation of noise; general discussion in three dimensions of the noise output of an electron gun; the one dimensional model, its justification and limitations; the transmission-line analogy; noise in the retarding-field diode and in the space-charge-limited equivalent diode of the electron gun of a traveling-wave amplifier; the conditions for minimum noise factor; modulation noise in a semiconductor and the transistor noise factor. (To be offered fall semester, alternate years.)

**699. Research Work in Electrical Engineering.** *Prerequisite: permission of program adviser. (To be arranged).*
Graduate students electing the course, while working under the general supervision of a member of the staff, are expected to plan and carry out the work themselves and to make reports in the form of theses.

**720. Electromagnetic Field Theory IV.** *Prerequisite: Elec. Eng. 620. (3).*
Individual and collective motions of charged particles in electromagnetic field. Absorption, propagation, scattering, and generation of radiation in plasmas. Least action and Fermat's principles, Eikonal Equations, and Hamilton's Canonical Equations of optics and mechanics. The concepts and techniques of Special Relativity and Lorentz Covariance are introduced.

**725. Methods of Solving Radiation and Scattering Problems.** *Prerequisite: Elec. Eng. 620 or equivalent. (3).*
Determination of approximate solutions of scattered electromagnetic fields from

simple and complex shapes which have been illuminated by electromagnetic energy, such as radio waves. Solutions of various radiation problems are obtained by using the reciprocity theorem, together with the techniques developed for the scattering problem. Simple and complex antenna shapes including slotted arrays are considered. The emphasis in this course will be on recent literature and in current research.

**735. Microwave Antenna Theory.** *Prerequisite: Elec. Eng. 531 and 620 or permission of instructor. (3).*
Methods of solution of microwave antenna design problems, reciprocity theorem, circuit relationships, impedance concept, reaction concept, slots, mutual coupling.

**802. Interdisciplinary Seminar in Communication Sciences I.** *Prerequisite: permission of instructor. (3).*
General aspects of human communication. Selected topics related to the application of information theory to psychology, speech, linguistics, logical nets, and communication engineering.

**803. Interdisciplinary Seminar in Communication Sciences II.** *Prerequisite: Elec. Eng. 802. (3).*
Continuation of Elec. Eng. 802.

**810(Astron. 810). Advanced Radio Astronomy Seminar.** *Prerequisite: Elec. Eng. 536 or permission of instructor. (2).*

**815. Seminar in Network Theory.** *Prerequisite: Elec. Eng. 515, or permission of instructor.* I and II. *(2).*
Study and discussion of topics in network theory. Topics will be chosen from the following: topological methods in analysis and synthesis, N-port synthesis, analysis and synthesis of time-varying networks, synthesis of active networks.

**820. Topics in Electromagnetic Field Theory.** *Prerequisite: Elec. Eng. 620. (3).*
Differential, integral, and variational formulation of field problem; classical solutions. Method of linear operators; discontinuous solutions and theory of distributions; propagations in random medium, coherent and incoherent discrete processes; approximate solutions; theory of multiple scattering and problem of radiative transfer.

**845. Seminar on the Theory of Adaptive and Optimalizing Control Systems.** *Prerequisite: Elec. Eng. 545 or Instr. Eng. 570 or permission of instructor. (2).*
Discussion of adaptive and optimalizing control-system concepts. This seminar may be repeated for credit.

**846. Seminar on Stability Theory and its Relation to Control-System Design.** *Prerequisite: Elec. Eng. 545 or Instr. Eng. 570 or permission of instructor. (2).*
Stability concepts; stability relative to initial condition; structural stability, stability of linear systems; Lyapunov's Second Method. Lyapunov functions; selection of Lyapunov functions; application to the design of control systems.

**865. Seminar on Research Topics in Computer Organization.** *Prerequisite: Elec. Eng. 565 or permission of instructor. (To be arranged.)*
Study and discussion of current research in computer organization, language, structure, and logic, with particular reference to recent periodical literature.

**883. Topics in Physical Electronics.** *Prerequisite: Elec. Eng. 380 or 580, and Math. 450. (2) without a laboratory; (3) with a laboratory. (2 or 3).*
Suggested topics for analysis: high pressure and high temperature plasmas, in-

cluding magnetohydrodynamic effects; interactions producing extreme electron temperatures; mean free paths and ion mobilities and ionization rates; ambipolar diffusions; probe measurements in gas discharges; initiation of microwave gas discharges; high density electron beam formation, focusing, hysteresis, and instability; the quantum-mechanics of electron emission; initial electron velocity effects; space charge suppression of slot noise. Lectures and optional laboratory.

**886. Special Topics in Microwave Circuits and Tubes.** *Prerequisite: Elec. Eng. 420 and 580 or permission of instructor.* I. *(To be arranged.)*
Selected topics of current interest.

**895. Seminar in Space Research.** *Prerequisite: permission of instructor. (2).*
Detailed analyses of objectives, procedures, and results of research being carried out at The University of Michigan. Topics will include the following: structure of the upper atmosphere; measurement of temperature, pressure, density, composition, and winds. The ionosphere; measurement of ion and electron density and temperature. Investigation of radio waves incident on the earth at frequencies absorbed by the ionosphere by means of instrumented satellites. Interpretation of infrared data from meteorological satellites. Research in attitude control of multistage sounding rockets.

**990. Doctoral Thesis.** I, II, and S.S. (to be arranged).

## ENGINEERING GRAPHICS

Drawing, the one universal language of all engineers regardless of native tongues, is presented at the college level, as distinguished from the technical or drafting levels. Engineers must be able to read drawings and, frequently, to make them. They are always dealing with drawings in one way or another.

The ability to visualize and think in three dimensions is essential to understanding atomic, molecular, crystallographic, nuclear, and outer-space relationships, as well as more commonplace ones. Such an ability is directly developed by the practice of thinking analytically to arrive at graphical results and, conversely, by the use of graphical representation to enhance and expand analytical visualization. These processes come into direct application in descriptive geometry as in few other courses of study.

Accuracy and neatness are essential to good engineering and are necessarily important aspects in the study of drawing.

**101. Engineering Drawing.** I, II, and S.S. *(3).*
Elementary college-level course. Use of instruments in mechanical drafting; techniques in freehand drawing; lettering practice; geometric construction; first principles of orthographic projection, pictorial drawing; sectional and auxiliary views; conventions and simplified representation; dimensioning and threads and fasteners; detail and assembly drawings, drawn both mechanically and freehand.

**102. Descriptive Geometry.** *Prerequisite: Eng. Graphics 101.* I, II, and S.S. *(3).*
Application of the principles of geometry and orthographic projection toward describing all engineering devices and objects accurately and usefully. The relationships of points, lines, and planes; the graphical measurement of distances and angles from all possible relative positions; the determination of intersections

of planes and curved surfaces with straight lines, planes, curved lines, and surfaces; tangent and secant surfaces; shape and size of plane areas and curved surfaces by development. Practical applications of descriptive geometry to engineering design problems.

**104. Geometry of Engineering Drawing.** *Prerequisite: Eng. Graphics 101.* I and II. *(2).*
Elementary principles of orthographic projection in representing relations of lines and planes, and in the graphical measurement of distances, angles, and areas. Constructions employing auxiliary views as utilized in engineering practice. Credit cannot be allowed for both this course and Eng. Graphics 102.

**141. Mechanical Drawing for Foresters.** II. *(1).*
Use of instruments, geometric constructions, lettering practice, orthographic projection, dimensioning, and elementary working drawings. As far as possible, drawing assignments are taken from material with which the forestry student will later have contact.

**232. Graphical Analysis and Computation.** *Prerequisite: permission of instructor.* II. *(2).*
Special geometrical constructions, graphical solutions of equations, theory of graphical scales and nomography, empirical equations, graphical calculus, and vector graphics. Theory and execution of methods followed by construction of working charts and computing aids.

**233. Advanced Engineering Drawing.** *Prerequisite: Eng. Graphics 102 or 104.* II. *(2).*
Advanced work in orthographic and pictorial representation, including engineering sketching; machine drawing; working drawings, both detail and assembly, with emphasis on auxiliary views and tolerance dimensioning; piping and structural layouts; creating and planning engineering devices.

**235. Production Illustration.** *Prerequisite: Eng. Graphics 101, or equivalent.* II. *(2).*
Advanced drawing, mechanical and freehand; lettering; emphasis on the use of orthographic, axonometric, and oblique projection in making various kinds of pictorial drawings, including sectional, exploded, assembly, and individual part views.

## ENGINEERING MECHANICS

**208. Statics.** *Prerequisite: preceded by Math. 116 and Physics 145, or written permission.* I and II. *(3).*
Fundamental principles of mechanics and their application to the simpler problems of engineering; forces, vector algebra, moments, couples, friction, hydrostatics, virtual work, and centroids.

**210. Mechanics of Material.** *Prerequisite: Eng. Mech. 208 and preceded or accompanied by Math. 214 or 215.* I and II. *(4).*
Application of mechanics to problems in stress and strain on engineering materials; resistance to direct force, bending, torque, shear, eccentric load, deflection of beams, buckling of columns, and compounding of simple stresses.

**212. Laboratory in Mechanics of Material.** *Prerequisite: preceded or preferably accompanied by Eng. Mech. 210.* I and II. *(1).*

Behavior of engineering materials under load in both the elastic and the plastic ranges; use of testing machines; use of mechanical, optical, and electrical strain measuring instruments; tension, compression, torsion, bending, and hardness tests; column experiments; demonstrations in photoelasticity and stress coat.

**218. Statics.** *Prerequisite: Physics 153, preceded or accompanied by Math. 116.* I and II. *(3).*

Basic principles of mechanics; laws of motion, concepts of statics, vectors and vector addition and products; moments and couples; resultants and equilibrium of general force systems; free body method of analysis; applications to simple problems in all fields of engineering; elementary structures, cables, friction, centroids, hydrostatics, stability of floating bodies, virtual work.

**219. Strength of Materials.** *Prerequisite: Eng. Mech. 218, preceded or accompanied by Math. 215.* I and II. *(4).*

Stress-strain relations, elastic and inelastic behavior of materials, combined stresses, introduction to theories of failure, statically determinate and indeterminate problems, axial stresses and strains including the thermal effect, torsion and bending of bars; shear center, deflection of beams, combined loading of a bar, buckling of columns, thick-walled cylinders.

**310. Statics and Stresses.** *Prerequisite: Physics 145 and Math. 214 or 216.* I and II. *(4).*

Fundamental principles of statics and their application to engineering problems; forces, moments, couples, friction, centroids, moment of inertia; application of statics to problems in stress and strain on engineering materials, including resistance to direct loads, bending, torque, shear, eccentric loads.

**314(Aero. Eng. 314). Structural Mechanics I.** *Prerequisite: Eng. Mech. 210 or 219.* I and II. *(4).*

Review of plane states of stress and strain; basic equations of plane elasticity and selected problems; failure criteria and applications; energy principles of structural theory; thin-walled beam theory.

**324. Fluid Mechanics.** *Prerequisite: Eng. Mech. 208 or 310 and Math. 214 or 216.* I and II. *(3).*

Principles of mechanics applied to liquids and gases. Dynamic similitude; special topics; manometers, Venturi and orifice meters, equilibrium of floating bodies, laminar and turbulent flow; resistance to flow, circulation, lift, boundary layers, free-surface flow, adiabatic flow of ideal gases in conduits.

**326. Fluid Mechanics.** *Prerequisite: Eng. Mech. 343 or 345, accompanied by Math. 216.* I and II. *(4).*

An introduction to the statics, dynamics, and thermodynamics of real and ideal fluids; laminar, turbulent, compressible and incompressible flows; the Euler, Bernoulli, and continuity equations; construction of flow nets; dimensional analysis and similitude applied to such subjects as flow in channels and conduits and lift and drag of bodies.

**328. Fluid Mechanics Laboratory.** *Prerequisite: preceded or accompanied by Eng. Mech. 324 or 326.* I and II. *(1).*

Visualizing flow of liquids; Reynolds' experiment; viscometry; hydrostatics; stability of floating bodies; photographing flow patterns; measuring flow and calibrating orifices, flow nozzles, Venturi meters; hydraulic jump and critical depth; resistance to flow, boundary layer, transition.

**343. Dynamics.** *Prerequisite: Eng. Mech. 208 or 310 and preceded by Math. 214 or 216.* I and II. *(3).*
Vectorial kinematics of moving bodies in both fixed and moving reference frames. Kinetics of particles, assemblies of particles and of rigid bodies with emphasis on the concept of momentum. Keplerian motion, moment of inertia, tensor and its transformations, elementary vibrations and conservative dynamic systems are treated as special topics.

**345. Dynamics.** *Prerequisite: Eng. Mech. 218, accompanied by Math. 216.* I and II. *(3).*
Kinematics, rectilinear and curvilinear motion, Coriolis' acceleration, kinetics of particles and bodies, d'Alembert's principle, momentum, conservative and non-conservative systems, impact, dynamic stresses, propulsion; vibrations of rigid bodies, vibrating mass systems, electrical and acoustical analogies, gyroscopes, balancing.

**402. Experimental Stress Analysis.** *Prerequisite: Eng. Mech. 210 or 219.* I. *(2).*
Review of plane stress-strain relationships, with mechanical, optical, and electrical resistance strain-measuring techniques; applications including strain rosettes; dynamic and transient strain and displacement measurements; brittle coatings and brittle models; fundamentals of photoelasticity. Laboratory sessions with assigned experiments. Recommended as a substitute for Eng. Mech. 210.

**403. Experimental Mechanics.** *Prerequisite: Eng. Mech. 210 and 343, and Elec. Eng. 316.* II. *(2).*
Theory and practice in the design and execution of experiments in engineering. Modeling theory. Probability and elementary statistics applied to data treatment; analysis, design and use of instruments for static or dynamic conditions, including measurement of strain, pressure, temperature, and viscosity. One-hour lecture and two-hour laboratory, with assigned experiments.

**411. Structural Mechanics.** *Prerequisite: Eng. Mech. 210 or 219.* I and II. *(3).*
Review of plane states of stress and strain. Basic equations of plane elasticity and selected problems. Failure criteria and applications. Energy principles of structural theory. Introduction to plate theory.

**412. Intermediate Mechanics of Material.** *Prerequisite: Eng. Mech. 210 or equivalent and Math. 403 or 404.* I and II. *(3).*
Classification of materials; elasticity, viscosity, plasticity. Analysis of simple combinations. Limit theory of plasticity. Introduction to general linear elasticity; plane solutions and torsion problem. Energy principles and application to approximate systems.

**413. Photoelasticity.** *Prerequisite: Eng. Mech. 210 and Math. 403.* I and II. *(2).*
Lectures and laboratory experiments covering the fundamentals of the photoelastic method of stress determination including the use of double refraction and interference of light, determination of the maximum shear stress, methods of separating the principal stresses, and three-dimensional photoelasticity. Models to suit interest of students.

**414(Aero. Eng. 414). Structural Mechanics II.** *Prerequisite: Eng. Mech. 314.* I and II. *(4).*
Introduction to plate theory. Stability of structural elements; columns and beam columns; plates in compression and shear; secondary instability of columns. Introduction to matrix methods of deformation analysis; structural dynamics. Lectures and laboratory.

**416. Stress Analysis.** *Prerequisite: Eng. Mech. 210. (2).*
Basic concepts of stress and strain in two dimensions; curved beams and beams on elastic foundations; fundamentals of photoelasticity.

**422. Intermediate Mechanics of Fluids.** *Prerequisite: Eng. Mech. 324 or equivalent and Math. 403 or 404.* I and II. *(3).*
Continuity, stream functions, vorticity; Euler and Bernoulli equations; irrotational flows, Laplace equation, conformal mapping, relaxation method; hydrodynamic forces and moments; compressible flows, method of characteristics; Navier-Stokes equations, elements of hydrodynamic stability, and turbulence; boundary layers, jets, wakes, drag.

**441. Intermediate Mechanics of Vibrations.** *Prerequisite: Eng. Mech. 343 or equivalent and Math. 403 or 404.* II. *(3).*
Free and forced vibration for lumped and continuous mechanical systems; vibration of multimass systems, strings, bars and plates; normal modes, mechanical impedance, vibration control; matrix methods; Rayleigh's Method and introduction to Lagrange's Equations.

**442. Intermediate Dynamics.** *Prerequisite: Eng. Mech. 343 or equivalent, Math. 450.* I. *(3).*
Vector mechanics for particle and rigid body motions. Lagrange's equations, Hamilton's principle, variational methods.

**514. Theory of Elasticity I.** *Prerequisite: Eng. Mech. 412 or equivalent.* I. *(3).*
Basic equations of three-dimensional elasticity. Variational principles, the plane problem, and torsion and bending of prismatic beams, with application of complex function theory.

**515. Theory of Plates.** *Prerequisite: Eng. Mech. 412 or equivalent.* II. *(3).*
Classical linear plate theory, with application to various shapes, boundary conditions, and loading systems; refinements to account for anisotropy, shear deformations, large deflections; plastic collapse and elastic instability.

**516. Theory of Shells I.** *Prerequisite: Eng. Mech. 412.* I. *(3)*
General theory for deformation of thin shells with small deflections; various approximate theories, including the membrane theory. Application to various shell configurations.

**518. Theory of Elastic Stability I.** *Prerequisite: Eng. Mech. 412 or equivalent.* I. *(3).*
Elastic and inelastic buckling of bars and frameworks; variational principles and numerical solutions; lateral buckling of beams. Instability of rings.

**519. Theory of Plasticity I.** *Prerequisite: Eng. Mech. 412 or equivalent.* II. *(3).*
Fundamentals of plasticity; stress-strain relations, yield criteria, and the general behavior of metals and nonmetals beyond proportional limit in the light of experimental evidence. Various approximate theories with emphasis on the theory of plastic flow. Application to problems of bending, torsion, plane strain and plane stress; technological problems.

**522. Mechanics of Inviscid Fluids I.** *Prerequisite: Eng. Mech. 422 and Math. 450.* II. *(3).*
Solution of Laplace's equation by various methods; added masses, Taylor theorem; forces and moments, Blasius and Lagally theorems; free-streamline flows, wave motion, vortex motion, and shear flows; theory of thin airfoils or projectiles; high speed flow.

**523. Mechanics of Viscous Fluids I.** *Prerequisite: Eng. Mech. 422 or equivalent and Math. 450.* I. *(3).*
Stress and rates-of-deformation tensors, dissipation function, exact solutions of the Navier-Stokes equations, very slow motion, boundary layers, jets and wakes, energy equation, forced and free convections, hydrodynamic stability, statistical theories of turbulence.

**524. Wave Motion in Fluids.** *Prerequisite: Eng. Mech. 422 or permission. (3).*
Surface waves in liquids, group velocity and dispersion; shallow-water waves, kinematic waves, method of characteristics; subcritical and supercritical flows; analogy between free-surface flows and gas flows; subsonic flows of a gas, hodographs, Molenbroek's transformation, Legendre's transformation, Chaplygin's treatment, Karman-Tsien method; supersonic flows, Riemann's nonlinear treatment of finite waves, nonlinear expansion flows, Pradtl-Busemann method of characteristics; shock waves; wave motion of a conducting fluid in an electromagnetic field.

**525. Mechanics of Control of Fluid Systems.** *Prerequisite: Math. 450.* II. *(2).*
Analysis of the dynamics of closed-loop feedback systems, pressure-controlled hydraulic systems, and velocity-control systems.

**527. Thermodynamics.** *Prerequisite: Math. 403 or 404.* I. *(2).*
Fundamental concepts; first and second laws of thermodynamics, equilibrium of homogeneous systems; applications to elastic and plastic deformations and fluid dynamics.

**529. Advanced Laboratory in Mechanics of Fluids.** *Prerequisite: Eng. Mech. 422 or permission of instructor.* II. *(2).*
Laboratory experiments designed to give the student an insight into the physical behavior of fluids and the role of experimentation in research. Experimental results are compared with existing theory whenever possible. Experiments include fundamental studies of free streamline flows, drag forces and moments, pressure distributions, thermal instability, slow-motion flows, and the Prandtl-Meyer flows.

**543. History of Dynamics.** *Prerequisite: Eng. Mech. 343 and Math. 403. (2).*
A review of the important publications in which the fundamental principles of dynamics were developed from Aristotle to Lagrange. The influence of astronomical theories on the development of dynamics.

**544. Dynamics and Stability of Rotors.** *Prerequisite: Eng. Mech. 441.* II. *(3).*
Problems of balance and vibration in turbine rotors and reciprocating engine moving parts, blade and disc vibrations, harmonic analysis, vibration dampers and absorbers, vibration-stress analysis.

**545. Vibrations of Continuous Media.** *Prerequisite: Eng. Mech. 412 and 441, or permission of instructor.* I. *(3).*
Wave motion and vibration of elastic systems, including strings, bars, shafts, beams, and plates. Problems in free and forced vibrations with various end conditions and types of loading; effect of damping on the motion; applications of Rayleigh-Ritz and other methods to the approximate calculation of frequencies and normal modes of nonuniform systems.

**547. Theory of Gyroscopes.** *Prerequisite: Eng. Mech. 441, or permission of instructor.* I. *(2).*
General theory of rigid-body rotational dynamics applied to gyroscopes of one

and two degrees of freedom. Various applications of gyroscopes to measurement and control problems.

**548. Micromechanics of Solids.** *Prerequisite: Eng. Mech. 432, Math. 552 or 554, or permission of instructor.* II. *(3).*
Dynamics of microscopic systems in the solid in relation to the macroscopic mechanics of continuous media. Elastic wave propagation through a vibrating lattice; electron, phonon, and defect motions; defect, disorder, and surface effects on the vibrational frequency spectrum; slow neutron scattering.

**555. Statistical Foundations of Mechanics.** *Prerequisite: Eng. Mech. 324 and 343 or equivalent, Math. 403 or 404.* II. *(3).*
The statistics and kinetics of microscopic systems in relation to the rheology of a Stokes fluid and the phenomonological mechanics of liquids and solids; conservation laws and their limits of validity; applications to the dynamics of fluids and solids.

***572. Intermediate Mechanics of Material I.** *(2).*

***573. Intermediate Mechanics of Material II.** *(2).*

***574. Intermediate Mechanics of Fluids I.** *(2).*

***575. Intermediate Mechanics of Fluids II.** *(2).*

**707. Theory of a Continuous Medium.** *Prerequisite: Eng. Mech. 412, 422, and permission of instructor. (3).*
General theory of a continuous medium and its specialization to elastic, fluid, plastic, and other special media; basic kinematics; stress and strain tensors and their invariants; conservation of momentum, conservation of energy; the restrictions placed upon the equation of state and the dissipation equations by the second law of thermodynamics.

**714. Theory of Elasticity II.** *Prerequisite: Eng. Mech. 514.* II. *(3).*
Three-dimensional elasticity problems. Derivation of approximate systems (plates, shells, etc.) from variational principles; introduction to nonlinear elasticity.

**716. Theory of Shells II.** *Prerequisite: Eng. Mech. 516.* II. *(3).*
Refinements in classical shell theory to account for anisotropy, shear deformation, thick shells. Nonlinear shell theory with particular reference to stability; plastic deformation of shells; dynamics of shells.

**718. Theory of Elastic Stability II.** *Prerequisite: Eng. Mech. 518.* II. *(3).*
Linear instability theory of plates and shells. Postbuckling analysis. Dynamic stability criteria. General instability theory in three-dimensional elasticity.

**719. Theory of Plasticity II.** *Prerequisite: Eng. Mech. 519.* I. *(3).*
Plastic theory for materials with isotropic hardening, kinematic hardening, and time dependence. Theories based on crystal slip; variational theorems; range of validity of total deformation theories. Theory of generalized stresses applied to circular plates; behavior at finite deflection; limit analysis of shells. Plane stress, plane strain, and axial symmetry. Plastic response to impact loads. Minimum weight design.

**721. Mechanics of Inviscid Fluids II.** *Prerequisite: Eng. Mech. 522 and 527, others by permission.* I. *(3).*

*For description, see Eng. Mech. 412 and 422 or Detroit Extension Service bulletin.

Theory of large-amplitude motion of fluids with variable density and entropy in a gravitational field, flow of heterogeneous fluids in porous media, gravity and sound waves in stratified fluids, stability of stratified fluids. Flow in a rotating system or a magnetic field.

**723. Mechanics of Viscous Fluids II.** *Prerequisite: Eng. Mech. 523.* II. *(3).*
Treatment of hydrodynamic equations in general co-ordinates by tensorial methods; gravitational, hydromagnetic, and surface-tension instabilities; instability of rotating fluids and of flow in porous media. Tollmien-Schlichting waves; instability of free-surface flows.

**741. Transient Motion and Vibration of Nonlinear Systems.** *Prerequisite: Eng. Mech. 441, Math. 447 and 450.* II. *(3).*
Transient motion in linear systems caused by forces or motions which are functions of time. Methods of treating the motions of nonlinear mechanical systems of one degree of freedom.

**745. Wave Motion in Continuous Media.** *Prerequisite: Eng. Mech. 441 or equivalent and permission of instructor.* II. *(3).*
Wave propagation in bounded and extended elastic media, including transmission, reflection, and refraction phenomena, transient-stress states, and analogies with acoustical and optical effects. Forced motion of continuous elastic systems such as plates, membranes, shells, and other forms.

**801. Seminar in Engineering Mechanics.** *Prerequisite: permission.* I and II. *(1 or 2).*
A series of weekly seminars. Students who contribute may elect one or two hours credit.

**911. Research in Mechanics of Solids.** I and II.
Research in theory of elasticity, plasticity, photoelasticity, structures, and materials. Special problems involving application of theory and experimental investigation.

**921. Research in Mechanics of Fluids.** I and II.
Analytical or experimental investigation of special problems in fluid flow, or intensive study of a special subject in fluid mechanics.

**941. Research in Dynamics.** I and II.
Original investigation in the field of body motions such as vibrations of mechanical systems, control problems, and other fundamental problems in the mechanics of rigid body motion.

**991. Doctoral Thesis.** I and II.
For doctoral candidates only, under supervision of the doctoral committee. Credit hours to be arranged.

## ENGLISH

The work offered in English prepares the student to write and speak effectively and to broaden and deepen his interest in literature. To these ends the department offers a variety of courses in written composition, speech, and literature.

It is presupposed that the student is adequately prepared in the fundamentals of English usage and that he has some knowledge of literature. Normally, a student will take ten hours of English: six hours in Group I, two hours in Group II, and two hours in Group III. The actual number of hours required, however, will depend in part upon the student's preparation and ability. The student of marked superiority may graduate with fewer hours in English; and, conversely, the student who needs additional training may be required to take additional hours of work in English. The student who enters with advanced credit will be required to show a proficiency equal to that of the student with the same number of hours of English credit earned in this College.

In his work for other courses in the engineering curriculum the student is also expected to maintain a satisfactory standard of English. If he fails to do so, he may be reported to the Assistant Dean who, with the student's program adviser and the chairman of the Department of English, may prescribe additional study.

GROUP I: BASIC COURSES

Courses in this group provide basic instruction and practice in writing and speaking. English 111 and 121 are elected during the first semester of the freshman year and English 112 during the second semester. Students with outstanding ability can be exempted from one or more of these courses, whereas students who are not prepared for English 111 may be required to take English 110 before taking English 111.

**110. Preparatory Composition.** I and II. *(3).*
A course in composition and reading for those in need of further preparation. Study and drill in diction, spelling, grammar, and punctuation; in the structure of the sentence, paragraph, and short essay; and in the techniques of reading.

**111. Freshman Composition I.** I and II. *(3).*
A course in the essentials of composition with stress on sentence structure, paragraph development, and theme organization. Spelling, diction, punctuation, and grammatical usage are considered as the need arises. Essays and some imaginative literature are analyzed to provide models and ideas for themes and to develop skill in reading.

**112. Freshman Composition II.** I and II. *(2).*
Continuation of English 111, with further stress on the essentials of composition but with the chief emphasis on various techniques of exposition and argument, such as analysis, analogy, comparison, and definition. The student also receives instruction and practice in writing research papers. As in English 111 essays and some imaginative literature are read and analyzed.

**121. Introductory Speech.** I and II. *(1).*
A course in the preparation and delivery and short expository and persuasive speeches. It is intended to help the student develop the ability to present his ideas to a group in an orderly and effective manner. Two hours of classwork.

GROUP I-A: NONTECHNICAL ELECTIVES FOR FRESHMEN (AND OTHERS WITH PERMISSION)

To serve the need for three-hour nontechnical electives in the humanities for freshmen (and others by permission of instructor), the English Department offers these three courses. They differ from Group II courses in three respects:

(1) there are no prerequisites; (2) they focus almost entirely on reading and discussion; (3) they use literature as a means of broadening the student's interest in and awareness of other humanistic subjects.

**114. Quest for Utopia.** II. *(3).*
Reading and discussion of some of the major efforts to chart the good society from Plato's *Republic* to Orwell's *1984*. The chief purpose of this survey of utopias and anti-utopias is to help the student assess the values in the present order.

**115. Literature and Philosophy.** II. *(3).*
Reading and analysis of literature as a means of introducing the student to some major philosophical issues. Authors to be read include Swift, Voltaire, Dostoevsky, and Mark Twain.

**116. Literature and Art.** II. *(3).*
Reveals and explains the close connections between the literature of a given period and its painting, sculpture, and architecture. The primary emphasis will be on reading with parallels illustrated in the fine arts.

GROUP II: INTERMEDIATE COURSES—LITERATURE

Group II provides courses in modern literature. To satisfy the Group II requirement, the student must either elect one of these courses or present a satisfactory equivalent. The courses in this group may also be taken for credit as nontechnical electives, and they are designed to help the student read with insight as well as pleasure and gain thereby a richer understanding of the nature of man and his world. Some writing is required in each of the courses.

**251. Modern Literature.** *Prerequisite: English 111, 112, and 121.* I and II. *(2).*
Reading and analysis of modern literature in its varied forms. The short story, novel, drama, and poem are treated as separate but interrelated means of expressing significant ideas. Faulkner, O'Neill, Frost, Shaw, Camus, and Chekhov are typical of the authors read.

**255. Modern Biography and Autobiography.** *Prerequisite: English 111, 112, and 121.* I and II. *(2).*
Reading and analysis of biographies and autobiographies of people who are in some way extraordinary. The subjects include such figures as Henry Ford, Benito Mussolini, P. T. Barnum, Benedict Arnold, and Mary Todd Lincoln.

**256. Modern Short Story.** *Prerequisite: English 111, 112, and 121.* I and II. *(2).*
Reading and analysis of modern short fiction by such significant American and European authors as Hemingway, Faulkner, Steinbeck, Maugham, and Joyce.

**263. Modern Drama.** *Prerequisite: English 111, 112, and 121.* I and II. *(2).*
Reading and analysis of representative modern plays, such as Ibsen's *Ghosts,* Shaw's *Candida,* O'Neill's *The Hairy Ape,* Williams' *The Glass Menagerie,* and Miller's *Death of a Salesman.*

**265. Modern Novel.** *Prerequisite: English 111, 112, and 121.* I and II. *(2).*
Reading and analysis of selected modern novels, both European and American. Writers whose works are most frequently assigned range from Zola and Flaubert to Faulkner and Hemingway.

**275. Modern Poetry.** *Prerequisite: English 111, 112, and 121.* I and II. *(2).*
Reading and analysis of the principal British and American poetry of the twentieth century. Robinson, Frost, Sandburg, Yeats, Auden, and Cummings are typical of the poets included in the course.

**299. Studies in Literature.** *Prerequisite: English 111, 112, and 121.* I. *(2).*
Open only to students whose native language is not English. An introduction to literature designed for the foreign student. The literature to be read, the method of presentation, and the reading and writing assignments are adapted to the particular needs of the foreign student.

GROUP III: ADVANCED COURSES—LITERATURE

*Open to juniors, seniors, graduate students, and others by permission.*

Group III courses in literature are specialized and intensive and require more maturity of the student than the courses in Group II. To satisfy the Group III requirement, the student must elect one of these courses, or present a satisfactory equivalent. The courses may also be taken for credit as nontechnical electives. All courses in this group may be taken for graduate credit, provided that the student has the approval of the instructor and his program adviser and provided that he completes additional work. Some writing is required.

**300. Studies in Literature.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.*
Open only to students whose native language is not English. An introduction to literature designed for the foreign student. The literature to be read, the method of presentation, and the reading and writing assignments are adapted to the particular needs of the foreign student.

**419. Major Speeches in American History.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II. (2; 3 with permission of instructor).*
A study of selected American speakers and their speeches in relation to the history of the times. The student will read significant speeches by such men as Daniel Webster, John C. Calhoun, Abraham Lincoln, William Jennings Bryan, Woodrow Wilson, and Franklin D. Roosevelt.

**455. American Folklore.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(2).*
The life and spirit of the American people as reflected in their folksongs and ballads, tales, legends, superstitions, proverbs and sayings, games, and customs. Extensive use will be made of regional and type collections and of recordings.

**457. Great Poetry.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(2).*
Reading and critical analysis of major poetry of the Western World from Homer to our own day, with the following as objectives: to acquaint the student with the worlds of belief, meaning, and beauty that have become a part of our Western tradition; to acquaint him with the nature and place of poetry by means of which he may more adequately understand and enjoy poetry; and to sharpen his powers of analysis and expression through writing assignments.

**458. Literature of Science.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(3).*

Reading and discussion of some classics of scientific literature, such as Darwin's *Origin of Species* and Freud's *A General Introduction to Psychoanalysis,* as well as writings by contemporary scientists on the nature of the scientific method, its application in various fields, and its limitations. The course is designed to extend the student's awareness of the impact of science, especially on man's conception of himself, his society, and his place in the universe.

**461. Shakespeare.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(2).*

Twelve or more of the principal plays, with a view to acquainting the student with something of Shakespeare's breadth and variety and illustrating the growth of his mind and art.

**462. Drama.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(2).*

Significant drama in classical, Elizabethan, neoclassic, and modern western civilizations.

**467. The Novel.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(2).*

Significant works of fiction from *Robinson Crusoe* to *Moby Dick,* such as *Tom Jones, Pride and Prejudice,* and *Vanity Fair,* with emphasis upon reading with understanding and delight.

**475. American Literature.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(2).*

Readings in the works of leaders in American thought from the early eighteenth century to the present. The course concentrates on those authors who best represent the changing ideals that have dominated American life in the past and that are important for an understanding of the contemporary American scene.

**485. Literary Masterpieces.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(2 or 3).*

Distinguished literary works in the western tradition, from the Greeks to our own day. Typical of the works that have been used are plays by Sophocles, Shakespeare, Ibsen, and Shaw; dialogues by Plato; selections from the Bible and from Machiavelli; poetry by Homer, Dante, Wordsworth, and Frost; fiction by Turgenev, Maupassant, and Katherine Mansfield.

**488. Literature and Modern Thought.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(3).*

The three objectives of the course are: (1) to acquaint the student with some major forces on modern thought, e.g., Marxism, Freudianism, and existentialism; (2) to acquaint him with significant works of literature which place these intellectual conceptions in humane perspective, e.g., fiction of Zola, Steinbeck, Koestler, Sartre; and (3) to encourage him to evaluate these ideas and the literature which expresses and comments upon them.

**492. Major American Writers.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(2).*

An intensive study of the works of two or three major American writers with emphasis on their ideas, their relationship to their period, their form of expression, and their literary significance. Writers are chosen who make possible an integrated exploration of significant cultural developments.

**493. Major European Writers.** *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(2).*
An intensive study of the works of two or three European writers with emphasis on their ideas, their relationship to their period, their form of expression, and their literary significance. Writers are chosen who make possible an integrated exploration of significant cultural developments.

GROUP IV: SPECIAL ELECTIONS IN SPEECH AND WRITING

**235. The Technical Article.** *Prerequisite: English 111 and 112.* I and II. *(2).*
An advanced composition course with special emphasis on the writing of technical and scientific articles for both professional and nonprofessional readers. The course includes some study of current scientific and technical articles from such periodicals as *Scientific American.*

**241. Public Speaking.** *Prerequisite: English 111 and 121.* I and II. *(2).*
Preparation and delivery of informative and persuasive speeches. The student is given opportunity, not only to improve his ability to speak effectively, and to listen critically, but also to choose his own subjects and to work with his own ideas, feelings, and experiences.

**436. Scientific and Technical Writing.** *Prerequisite: English 111, 112, and 121.* I and II. *(2).*
The fundamentals of scientific and technical writing with emphasis on clear and orderly exposition.

**441. Argumentation and Debate.** *Prerequisite: English 111, 112, and 121.* I and II. *(2).*
Training in the organization and the delivery of the principal types of persuasive speeches, with emphasis on conference speaking and debating.

## GEOLOGY AND MINERALOGY*

Associate Professor Eschman; Professors Arnold, Briggs, Denning, Goddard, Heinrich, Hibbard, Kellum, Kesling, Landes, Slawson, Stumm, Turneaure, and Wilson; Associate Professors Dorr and Kelly; Assistant Professors Cloke and DeNoyer; Instructors Macurda and Peacor; Lecturer Reimann.

**111. Introductory Geology.** *Not open to those who have had Geol. 219.* I. *(4).*
An introduction to science through geology. The study of the materials making up the earth, the processes which act upon them, and the effects these processes have on the earth's surface; the development of the tools for the interpretation of the history of the earth; and the major geologic concepts which make geology unique from the other natural sciences. One or more Saturday field trips will be required. Lectures, laboratory, and field trips for an average weekly total of seven hours.

**218. Geology for Engineers.** II and S.S. *(4).*
Geologic processes with special emphasis on structural geology, ground water,

*College of Literature, Science, and the Arts.

soil genesis, and the relation of geology to engineering problems. Laboratory includes rock and mineral identification, and the interpretation of geologic and topographic maps and aerial photographs. Geol. 218 is required of students in civil engineering and is open to others as an elective. Lectures, laboratory, and field trips.

**219. Geology and Man.** *Not open to freshmen, or to those who have had Geol. 111.* II. *(4).*
Geologic processes and their effect on civilization. Lectures and demonstrations.

For other courses in geology for which students of engineering are eligible, see the *Announcement* of the College of Literature, Science, and the Arts. It is suggested that Geol. 112, Introductory Geology; Geol. 280, Minerals and World Affairs; and Geol. 447, Ground Water Geology, are especially useful for engineering students.

## INDUSTRIAL ENGINEERING

**112. Industrial Administration.**
Extension course covering principles of management, business games, budgeting control, purchasing, ethics, research and development, and policies and procedures.

**114. Introduction to Management Sciences**
Extension course version of Ind. Eng. 401.

**116. Work Measurement and Wage Administration.**
Extension course covering Ind. Eng. 445 and 463.

***400. Industrial Management.** *Prerequisite: junior standing or permission of department.* I and II. *(3).*
Management problems and methods involved in the operation of manufacturing institutions, including location, layout, equipment selection, methods, work measurement, methods of wage payment, inspection, organization procedures, production and material control, budgets. A Business Game is used to study dynamic aspects of industrial decisions.

**401. Introduction to Management Sciences.** *Prerequisite: preceded or accompanied by Math. 464 and Ind. Eng. 472, or permission of department.* II. *(3).*
Current studies in management problems, including management games, management design and control of research programs, organization and information theories.

**431. Administrative Procedures.** *Prerequisite: Ind. Eng. 400 and 463.* I and II. *(3).*
Management organization structures, personnel relations, supervisory methods and procedures, and general management control methods.

***433. Human Factors in Engineering Systems.** *Prerequisite: Ind. Eng. 400 or permission of instructor.* I. *(3).*
The application to engineering of the information available concerning vision,

*Students not enrolled in the industrial engineering program and not presenting the usual prerequisite may elect courses indicated by * with the permission of the department.

illumination, color, noise, atmospheric conditions, physical measurements, and the arrangement of controls and equipment in the areas of work place and equipment design. Emphasis will be placed on sources and methods of collection and analysis of the available information.

*441. **Production and Inventory Control I.** *Prerequisite: Ind. Eng. 472 and 473 or graduate standing.* I and II. *(3).*
The methods and concepts involved in the forecasting, routing, scheduling, dispatching, planning, and controlling production systems as well as the contemporary methods of implementation and control of inventory and distribution systems.

447. **Plant Layout and Materials Handling.** *Prerequisite: Ind. Eng. 451, 463, and 441.* I and II. *(3).*
Analysis and planning of the layout of physical facilities. The analysis and selection of materials handling equipment as influenced by material, processing, production equipment, building, economic considerations, and related factors.

451. **Engineering Economy I.** *Prerequisite: Econ. 401 and Bus. Ad., General 454.* I and II. *(2).*
Economic selection of equipment, consideration of costs, methods of financing, depreciation methods, and the economics of production estimating.

463. **Work Methods and Measurements I.** *Prerequisite: Ind. Eng. 400 and one semester of statistics.* I and II. *(3).*
Analysis and development of operating methods, development of work place layouts and labor standards by use of the principles of motion economy, predetermined time standards, and time study.

464. **Work Simplification.** *Prerequisite: Ind. Eng. 463 or permission of department.* II. *(3).*
Application of tools and techniques of work simplification to improve work systems requiring the integration of people, machines, methods, and procedures. Current literature and cases are studied.

466. **Quality Control.** *Prerequisite: Ind. Eng. 461.* II. *(3).*
Surveys of current practices in acceptance sampling and control charts. Some of the more important quality measuring equipment is discussed and used in experiments. Emphasis is placed on the economics of alternative quality control procedures. Two-hour lecture and two-hour demonstration.

472. **Operations Research.** *Prerequisite: preceded or accompanied by Math. 463 or 465.* I and II. *(3).*
Introduction to operations research; the methodolgy of mathematical models and its application to various industrial problems, including queueing theory, game theory, linear programming, inventory theory, and Monte Carlo processes. Two one-hour lectures and a two-hour recitation section.

473. **Data Processing.** *Prerequisite: Math. 216 and 273 or equivalent.* I and II. *(3).*
The use of data processing methods in industrial systems and an introduction to computer simulations of industrial operations. Two-hour lecture and two-hour demonstration.

491. **Study in Selected Industrial Engineering Topics I.** *Prerequisite: permission of department.* I and II. *(To be arranged, 3 maximum).*

*Students not enrolled in the industrial engineering program and not presenting the usual prerequisite may elect courses indicated by * with the permission of the department.

Individual or group study, design, or laboratory research in a field of interest to the student. Topics may be chosen from any of the areas of industrial engineering including management, work measurement, methods, organization, industrial sciences, industrial mathematics, systems, and procedures.

**522. Theories of Administration.** *Prerequisite: Ind. Eng. 431 or graduate standing.* II. *(3).*
Provides insight into the present theories concerning the administration of research and industrial organizations. Decision criteria, conflict resolution, status systems, concepts of organization, communications, efficiency criteria, wage concepts, problems of change, and aspects of motivation are presented and discussed.

**523. Great Works of Scientific Management.** *Prerequisite: graduate standing.* II. *(2 or 3).*
Origins and creative processes of the industrial engineering profession. The works of the founders of scientific management and original papers by outstanding men in the field are studied and discussed.

**524. Industrial Systems—Field Work.** *Prerequisite: Ind. Eng. 463.* I and II. *(3).*
Principles of management are applied to specific problems in industrial operations. Inspection trips to manufacturing plants, with problems and discussions based on these trips. A fee is required.

**527. Decision Simulations.** *Prerequisite: Ind. Eng. 472 and 473 or permission of department.* I. *(3).*
Design of representative total enterprise and functional decision simulations. Relation between game theory and decision simulations for research in bargaining, competition, and economics. Applications to industrial systems design and to training.

**528. Industrial Engineering Problems.** *Prerequisite: Ind. Eng. 400.* I and II. *(3).*
Problems and the application of the principles of industrial engineering, using the case method in solving typical management situations. The application of engineering methods to the study and analysis of management in an era of rapid scientific and technical advance.

**533. Problems Concerning Human Factors in Engineering Systems.** *Prerequisite: Ind. Eng. 433 or permission of department.* II. *(3).*
Problems and field exercises on the application of human factors to engineering systems. Students will formulate problems, select the experimental or other procedures for their solution, and report the findings.

**541. Analysis of Inventory Systems I.** *Prerequisite: Ind. Eng. 472 or permission of department.* I and II. *(3).*
The study of models for control of single item inventory. Deterministic lot size models, reorder point and periodic models with probabilistic demand. Extensions to dynamic inventory problems and analysis of steady state behavior using dynamic programming.

**542. Analysis of Inventory Systems II.** *Prerequisite: Ind. Eng. 541 and one year of statistics.* I. *(3).*
Continuation of Ind. Eng. 541. Inventory and production control models for systems with multiple items and with stations in series. Applications of linear and nonlinear programming to production smoothing and economic lot scheduling.

**546. Industrial Procurement.** *Prerequisite: Ind. Eng. 400.* I. *(3).*
Consideration of proper selection of sources of supply, price, and value analysis.

Standards and specifications. Purchasing department organization, buying policies. Case problems will be presented and discussed in detail.

**547. Plant-Flow Analysis.** *Prerequisite: Ind. Eng. 447, 472, and 473, or permission of department.* II. *(3).*
Study of assembly line balancing and machine loading, optimal path and network flow analysis using integral linear programming approaches. Equipment and activity location problems. Use of simulation in plant layout and scheduling studies.

**551. Engineering Economy II.** *Prerequisite: Ind. Eng. 451, or permission of department.* II. *(2 or 3).*
Economic analysis procedures relating to company growth, consideration of various replacement models, product and new enterprise analysis, capital budgeting. Case problems.

**561. Analysis of Industrial Experiments.** *Prerequisite: six hours of statistics.* II. *(3).*
Analysis of variance and regression analysis with application to industrial experiments. Two-hour lecture and two-hour demonstration.

**562.* **Industrial Systems—Field Work.** *Prerequisite: Ind. Eng. 463.* I. *(3).*
Principles of industrial systems and instrumentation are applied to specific problems in factory operation. Inspection trips to manufacturing plants with problems and discussion based on these trips. A fee is required.

**563. Work Methods and Measurements II.** *Prerequisite: Ind. Eng. 463.* I. *(2 or 3).*
Application of work sampling and memo-motion techniques as methods of work measurement; use of standard data-time standards and their determination by actual time-study, motion pictures, predetermined time-standards systems. Recitations and demonstrations.

**571. Queueing Systems Analysis I.** *Prerequisite: one year of statistics.* I. *(3).*
Simple single channel and multichannel queueing problems subject to Poisson input and negative exponential service times. Waiting times, busy period lengths, and state probabilities. General service time, systems, and Pollaczek's formula. Applications and extensions.

**572. Optimization in General Systems.** *Prerequisite: Ind. Eng. 473, Math. 517, or Ind. Eng. 575.* II. *(2 or 3).*
The problem of searching for an optimum policy when it cannot be solved by a standard programming code. Various general extreme-value search procedures, with and without estimation errors, and self-improving codes are considered.

**573. Simulation.** *Prerequisite: Ind. Eng. 473.* I. *(3).*
The use of a digital computer as a simulator of industrial processes. Construction of flow charts, fixed time increment and time status register methods of organization. Experimental designs for computer experiments are considered and students will run simple simulations.

**575. Linear Programming.** *Prerequisite: Ind. Eng. 472 or permission of department.* I. *(3).*
An introduction to programming. Primary attention is focused on linear programming. The abstract structure of the problem is discussed. A number of

*Students not enrolled in the industrial engineering program and not presenting the usual prerequisite may elect courses indicated by * with the permission of the department.

examples of uses of linear programming are introduced. Machine codes for solution are discussed and used.

**576. Nonlinear Programming.** *Prerequisite: Ind. Eng. 472 and six hours of statistics or permission of department.* II. *(3).*
Various integer and nonlinear problems. Gradient methods and the concepts of dynamic programming.

**591. Study in Selected Industrial Engineering Topics II.** *Prerequisite: Ind. Eng. 491.* I and II. *(To be arranged).*
Continuation of Ind. Eng. 491.

**631. Advanced Management Controls.** *Prerequisite: Ind. Eng. 431 or permission of department.* I. *(3).*
Studies of current methods for analyzing management control problems. The course uses actual cases as well as current publications and consists of further investigations and solution of those cases.

**641. Production and Inventory Control II.** *Prerequisite: Ind. Eng. 441 and one year of statistics.* II. *(3).*
The use of operations research techniques in production smoothing and scheduling. Applications of mathematical methods of sequencing and loading to optimization of facility utilization, interaction with inventory policies, and design of complex production-control systems.

**644. Production Design.** *Prerequisite: Ind. Eng. 447 and 524 or permission of department.* II. *(3).*
The co-ordination of product design with the necessary manufacturing processes. Evaluation of the available facilities is made with possible alternatives to aid management decisions. Case studies are selected from actual industrial situations.

**645. Executive Compensation and Incentives.** *Prerequisite: Ind. Eng. 445.* I. *(3)*
Considerations in the selection and design of executive salary and fringe benefit policies. Problems of motivation and morale, development, recruitment and performance measurement. Effect of management environment on performance.

**649. Automatic Process Control I.** *Prerequisite: Math. 216, Mech. Eng. 381, and Ind. Eng. 473.* I. *(3).*
Introduction to automatic control of manufacturing processes; Laplace transformations and their application to design of process control systems; numerically controlled machine tool synthesis, application and programming problems.

**671. Queueing Systems Analysis II.** *Prerequisite: Ind. Eng. 571 or permission of department.* II. *(3).*
Multichannel queues, Erlang input and service times. Embedded Markov chain analysis and inclusion of supplementary variables. Lindley's Integral Equation, time dependent solutions and approximations, elements of renewal theory, Markov chains, and the Feller-Kolomogorov equations.

**691. Graduate Study in Selected Problems.** *Prerequisite: permission of graduate committee.* I and II. *(To be arranged).*

**741. Industrial Dynamics.** *Prerequisite: Ind. Eng. 641 or permission of department.* I. *(3).*
Concerned with the problems involved in planning and controlling industrial change. Considers the firm as a unit continuously integrating production, market-

ing, investment, and research operations. Computer simulations are used to study the behavior of the firm under alternative policies.

**749. Automatic Process Control II.** *Prerequisite: Ind. Eng. 649.* II. *(3).*
Continuation of Ind. Eng. 649 into study of multiple process system control and use of real time computers.

**752. Replacement and Maintenance.** *Prerequisite: Ind. Eng. 451 and 671.* II. *(3).*
Interrelation of equipment and maintenance policies, effects of uncertain product demands and possible equipment design changes on replacement policies, preventive maintenance policies and echelon maintenance systems.

**806. Seminar in Special Industrial Engineering Topics.** *Prerequisite: Ind. Eng. 463 or permission of department.* II. *(1 or 2).*

**819. Seminar in Stochastic Programming I.** *Prerequisite: permission of department.* I. *(1 or 2).*

**820. Seminar in Stochastic Programming II.** *Prerequisite: permission of department.* II. *(1 or 2).*

**836. Seminar in Human Factors Engineering.** *Prerequisite: Ind. Eng. 433 or Psych. 560.* I and II. *(To be arranged).*
Case studies of techniques used in the human engineering field. Reading, surveys, and reports on the areas of specific interest of the student.

**876. Seminar in Operations Research I.** *Prerequisite: permission of department.* I. *(1 or 2).*

**878. Seminar in Operations Research II.** *Prerequisite: permission of department.* II. *(1 or 2).*

**906. Research in Industrial Engineering.** *(To be arranged).*

**992. Thesis Project.** *(To be arranged).*

## INSTRUMENTATION ENGINEERING

**510. Applications of the Electronic Differential Analyzer I.** *Prerequisite: a course in differential equations.* I and II. *(3).*
Basic theory and principles of operation of electronic differential analyzers. Applications to one and two degree-of-freedom vibration problems, automatic control systems, heat-flow, eigenvalue problems, nonlinear vibration problems, and other selected topics. Lecture and laboratory. Laboratory consists of the solution of problems on the electronic differential analyzer.

**530. Probability in Instrumentation.** *Prerequisite: Math. 450.* I and II. *(2).*
Probability theory and probability distributions as applied to measurements; averages, moments, correlation, and independence; the gaussian distribution; statistics of measurements; propagation of precision indices; maximum likelihood estimation and confidence intervals; least squares fitting of data; reliability.

**570. Principles of Automatic Control I.** *Prerequisite: Math. 404 or equivalent.* I and II. *(3).*

Transient and steady-state analysis of linear control systems; transfer operators; stability determination. Synthesis of linear control systems using the root-locus diagram. Nyquist plots, and gain-phase methods. Analysis of nonlinear control systems, including phase-plane and describing-function methods.

**571. Automatic Control Laboratory I.** *Prerequisite: preceded or accompanied by Instr. Eng. 570.* I and II. *(1).*
Introduction to the differential analyzer; its application to simulation of control systems presented in Instr. Eng. 570; the differential analyzer as a design tool. Examples of actual feedback systems, a.c. carrier systems.

**610. Applications of the Differential Analyzer II.** *Prerequisite: Instr. Eng. 510 or equivalent. (3).*
Differential analyzer solutions of a wide variety of static and dynamic engineering problems. Solution of linear and nonlinear automatic control problems. Simulation of the six degree-of-freedom dynamic rigid-body equations. Solution of linear and nonlinear partial differential equations using eigenvalue and difference techniques. Error analysis of differential analyzer solutions. Lecture and laboratory.

**612. Design of Electronic Analog Computers.** *Prerequisite: Elec. Eng. 438 or equivalent and Instr. Eng. 570 or Elec. Eng. 445. (3).*
Theory of operational amplifiers, including stability, reliability, and drift-effects and their influence on d.c. amplifier circuitry. Drift-stabilized d.c. amplifiers. Design of integrators, summers, and operational amplifier circuits. Design of servo-multipliers, time-division multipliers, function-generators, drift-stabilized power supplies, and other selected topics. Lectures and laboratory.

**620. Introduction to Nonlinear Systems.** *Prerequisite: Math. 404 and 450.* I and II. *(3).*
Study of systems represented by nonlinear autonomous (unforced) differential equations, including the following: concept of phase space; equilibrium points and their stability; conservative systems; limit cycles; jump phenomena; Van der Pol's equation; index of Poincare; theorems of Bendixson; the direct stability method of Liapunov. Many physical examples are used to illustrate the theory. Solutions are illustrated on the electronic differential analyzer.

**621. Simulation and Solution of Nonlinear Systems.** *Prerequisite: Instr. Eng. 510 and preceded or accompanied by Instr. Eng. 620 or permission of instructor. (1).*
Supervised work on assigned problems and problems of interest to the student of the types treated in Instr. Eng. 620 and 720. The principal tool used is the electronic differential analyzer.

**630. Random Processes in Linear Systems.** *Prerequisite: Math. 448 and a course in probability.* I and II. *(2).*
The concept of random signals and noise as applied to problems in communication and control; autocorrelation functions and wide-sense stationarity; the random telegraph wave, amplitude and phase modulation by random signals, and other examples; the notion of ergodicity and experimental measurement of autocorrelations; spectral density and its computation; linear systems with noise or random signal inputs; representation of band-pass filter outputs; design of simple optimum (Wiener) predictors.

**640. Information Theory and Data Transmission.** *Prerequisite: Instr. Eng. 530, Elec. Eng. 438, and Math. 448. (3).*

Role and characteristics of transmission links; modulation and multiplex theory in the light of signal-to-noise improvement, crosstalk, and improvement thresholds. Modulation and multiplex methods include amplitude, frequency, phase, subcarrier, pulse-amplitude, pulse-width, pulse-position, and pulse-code. Information efficiencies of the above methods; transducers and various methods of data recording.

**641. Radio Telemetry Laboratory.** *Prerequisite: to be taken concurrently with or following Instr. Eng. 640. (1).*
Laboratory experiments involving the various modulation and multiplex methods and associated instrumentation described in Instr. Eng. 640.

**660. Theory and Design of Measuring Systems.** *Prerequisite: Instr. Eng. 630 and Math. 448. (2).*
The nature of measurement, dimensional analysis and units, physical theories and models. Analysis of dynamic response and errors. Statistical aspects of measurement including estimation of parameters and information theory. Design of measuring systems. Analysis of instruments and systems to measure such things as displacement, velocity, acceleration, and orientation.

**661. Measurement Laboratory.** *Prerequisite: to be taken concurrently with or following Instr. Eng. 660. (1).*
Laboratory experiments covering the measurement theory given in Instr. Eng. 660.

**670. Principles of Automatic Control II.** *Prerequisite: Instr. Eng. 570 and Math. 448 or equivalent.* I and II. *(3).*
Time domain description of linear and nonlinear systems; system state, vector differential equations, matrix methods for solution of linear systems. Time domain design procedures. Application of Liapunov's direct method to the stability analysis and design of linear and nonlinear systems. State space treatment of nonlinear systems; optimum systems, the Pontryagin principle. Sampled data control systems: the z-transform, the advanced z-transform, stability determination, time and frequency domain synthesis procedures, the digital computer as a control element.

**671. Automatic Control Laboratory II.** *Prerequisite: preceded or accompanied by Instr. Eng. 670.* I and II. *(1).*
Design and use of operational amplifiers as control system elements. Experiments on the describing function, simulation of nonlinear systems, the Pontryagin principle, sampling, and sampled data feedback systems.

**700. Theory of Linear Time-Variant Systems.** *Prerequisite: Math. 448. (2).*
Linear time-variant systems with a finite number of degrees of freedom; general theory of linear dynamical systems, Green's function, adjoint systems, perturbation equations and methods, Floquet theory, the Brillouin-Wentzel-Kramers method, matrix methods, the time-variant impulse response and transfer function, operational methods, and computer techniques. Applications to automatic control and filtering. Use of electronic differential analyzer for the solution of problems is demonstrated.

**720. Theory of Nonlinear System Response.** *Prerequisite: Instr. Eng. 620. (2).*
Principally considered are forced systems with nonlinearities and a finite number of degrees of freedom, as represented by systems of nonlinear ordinary differential equations containing functions of the independent variable. Harmonic

and subharmonic response and synchronization and entrainment of oscillatory systems are considered. Various methods of analysis are treated.

**730. Random Processes in Systems Analysis.** *Prerequisite: Instr. Eng. 630 or equivalent, Math. 448. (3).*
Axiomatic treatment of probability and random processes; stationarity and ergodicity; characteristic functions; multivariate gaussian distributions and moments; linear and nonlinear systems with gaussian inputs; estimation of spectra from measurements; Poisson processes and the shot effect; integral equations for filtering and prediction; application of the Karhunen-Loeve expansion to the design of optimum systems.

**732. Special Topics in Random Processes.** *Prerequisite: Math. 448 or equivalent; Instr. Eng. 730 or Elec. Eng. 634 or equivalent. (3).*
Topics of current research interest to be selected from among the following: detection theory, nonlinear devices with random inputs, generalizations of Wiener optimum filtering, estimation of spectra, noise in sampled data systems.

**771. Principles of Automatic Control III.** *Prerequisite: Instr. Eng. 670, Math. 448, preceded or accompanied by Instr. Eng. 630, or permission of instructor. (3).*
Review of problems in modern control theory. Foundations: mathematical models of physical systems, matrices and finite dimensional vector spaces, solution of equations of motion. Some linear control problems; the concept of controllability. Optimum control theory: the calculus of variations, the principle of optimality, the Hamilton-Jacobi equation, the Pontryagin principle, existence theory and related topics, applications. The computation of optimal controls, including the gradient method and dynamic programming. Stochastic and adaptive problems.

**772. Special Topics in Automatic Control.** *Prerequisite: Instr. Eng. 771 or permission of instructor. (To be arranged).*
Topics of current research interest to be selected from such areas as: computer control, multivariable system design, theory of optimalizing systems, and theory of adaptive and stochastic systems.

**800. Seminar.** *(To be arranged).*

**810. Seminar on Electronic Analog Computers.** *Prerequisite: open only to graduates and seniors who receive special permission. (To be arranged).*
Study of selected topics in design and application of electronic analog computers.

**820. Seminar in Nonlinear Systems.** *(To be arranged).*

**830. Seminar in Random Processes.** *(To be arranged).*

**840. Seminar in Data Transmission.** *(To be arranged).*

**870. Seminar in Automatic Control.** *(To be arranged).*

**900. Directed Study.** *(To be arranged).*
Individual study of specialized aspects of instrumentation engineering.

**902. Research.** *(To be arranged).*
Specialized individual or group problems of research or design instrumentation supervised by a member of the staff.

## MATHEMATICS*

Professor Hay; Professors Bartels, Brumfiel, Cesari, Churchill, Coburn, Copeland, Craig, Darling, Dolph, Dwyer, Fischer, Gehring, Halmos, Heins, Higman, P. S. Jones, Kaplan, LeVeque, Lewis, Lyndon, McLaughlin, Mayerson, Nesbitt, Piranian, Rainville, Reade, Rothe, Savage, Thrall, Wendel, and Wilder; Associate Professors A. Brown, M. Brown, Clarke, Dushnik, Galler, Halpern, Harary, Hughes, Kazarinoff, Kincaid, Leisenring, Raymond, Ritt, Shields, Titus, Ullman, and Wesler; Assistant Professors Dickson, Duren, Eggan, Goldberg, Hedstrom, Hicks, Hill, D. A. Jones, Kister, Lee, Livingstone, Low, Minty, Ramanujan, and Rosen; Instructors Bennett, Cohn, Douglas, Gundy, Krause, Natzitz, O'Neill, Pearcy, Smith, and Smoller. Lecturer Arden.

**105(101). Algebra and Analytic Trigonometry.** *Prerequisite: one to one and one-half units of geometry, and one to one and one-half units of algebra.* I and II. *(4).*
Number systems; factoring; fractions; exponents and radicals; systems of equations; linear, quadratic, trigonometric, exponential, and logarithmic functions, their graphs and properties; triangle solutions.

**107(103). Trigonometry.** *Prerequisite: one and one-half to two units of algebra, and one to one and one-half units of geometry.* I and II. *(2).*
Includes the trigonometry of Math. 105.

**115(233). Analytic Geometry and Calculus I.** *Prerequisite: one and one-half to two units of high school algebra, one to one and one-half units of geometry, one-half unit of trigonometry.* I and II. *(4).*
Review of school algebra, binomial theorem; functions and graphs; derivatives, differentiation of algebraic and trigonometric functions, applications; definite and indefinite integrals, applications to polynomial functions.

**116(234). Analytic Geometry and Calculus II.** *Prerequisite: Math. 115.* I and II. *(4).*
Differentiation and integration of logarithmic and exponential functions; formal integration; determinants; polynomials and curve sketching; conic sections; rotation of axes.

**185, 186(335, 336). Analytic Geometry and Calculus I and II.** *Prerequisite: permission of the Honors or the Unified Science counselor, or instructor.* 185, I; 186, II. *(4 each).*
For students well-qualified in mathematics. Material covered in the sequence Math. 185, 186, 285 is approximately that included in Math. 115, 116, 215, and 216.

**195, 196(298, 299). Analytic Geometry and Calculus.** *Prerequisite: permission of the Honors counselor or instructor.* 195, I; 196, II. *(4 each).*
For superior students having outstanding high school records in mathematics. The sequence Math. 195, 196, 295, 296 includes the content of Math. 115, 116, 215, 216, 451, with deeper penetration into many topics and with additional material.

*College of Literature, Science, and the Arts. Other courses in mathematics are listed in the *Announcements* of that College and of the Horace H. Rackham School of Graduate Studies.

**213(352). Calculus I.** *Prerequisite: a semester of college analytic geometry.* I and II. *(5).*
Basic calculus of functions of a single variable. Differentiation and integration of elementary functions, differentials; arc length; applications. Followed by Math. 214.

**214(364). Calculus II.** *Prerequisite: Math. 213.* I and II. *(5).*
Physical applications of integration; infinite series; calculus of functions of several variables; first-order differential equations, linear differential equations with constant coefficients.

**215(371). Analytic Geometry and Calculus III.** *Prerequisite: Math. 116.* I and II. *(4).*
Polar co-ordinates; complex numbers; two- and three-dimensional vectors; solid analytic geometry; partial derivatives; multiple integrals.

**216(372). Calculus and Differential Equations.** *Prerequisite: Math. 215.* I and II. *(4).*
Infinite series; complex numbers and elementary functions; first-order differential equations, linear differential equations; series solutions.

**273(373). Elementary Computer Techniques.** *Prerequisite: to be preceded by or taken concurrently with Math. 186, 196, 213, or 215.* I and II. *(1).*
To cover mathematical methods used on electronic computers and the ways one communicates with a computer. Students will have the opportunity to write a program for the computer.

**285(337). Analytic Geometry and Calculus III.** *Prerequisite: Math. 186.* I. *(4).*
Continuation of the sequence Math. 185, 186.

**286. Differential Equations.** *Prerequisite: Math. 285.* II. *(3).*
For well-qualified students. Material covered is approximately that included in Math. 405, with some deeper penetrations.

**295, 296, 495(397, 398, 399). Analysis I, II, III.** *Prerequisite: Math. 195, 196.* 295, I; 296, II; 495, I. (295, 296, *4 each;* 495, *3).*
Designed primarily for mathematics honors students who have had Math. 195 and 196. The material covered is approximately that of Math. 216, 403, and 451, but there is a deeper penetration into many topics.

**403. Introduction to Differential Equations.** *Prerequisite: freshman and sophomore mathematics, including a full treatment of calculus.* I and II. *(3; 2 for students with full credit for Math. 214 or 216).*
Solutions and applications of differential equations of the first order; linear equations with constant coefficients; linear equations of the second order; solution by the power series method; applications.

**404. Differential Equations.** *Prerequisite: Math. 214 or 216.* I and II. *(3).*
Systems approach to linear differential equations and physical applications. Simultaneous linear equations, solution by matrices. Power series solutions. Numerical methods. Phase plane analysis of nonlinear differential equations.

**405. Differential Equations.** *Prerequisite: freshman and sophomore mathematics, including a full treatment of calculus.* I. *(4; 3 for students with full credit for Math. 214 or 216).*
The material on differential equations covered in Math. 214 or 216, and 404.

**412. Theory of Equations and Determinants.** *Prerequisite: to be preceded or accompanied by Math. 214 or 216.* I and II. *(3).*
Polynomials, partial fractions, complex numbers, determinants, linear equations and introduction to matrices, solution of polynomial equations.

**425(429). Mathematical Theory of Probability I.** *Prerequisite: Math. 214 or 216.* I. *(3).*
Sample spaces, axioms of probability, combinatorial and geometrical probability. Random variables, expectations. Independence, conditional probability, Bayes' theorem. Markov chains. Continuous and discrete distribution functions; various special distributions. Sequences of independent trials, random walks. DeMoivre-LaPlace theorem, weak law of large numbers.

**426(430). Mathematical Theory of Probability II.** *Prerequisite: Math. 425 and either 450 or 451.* II. *(3).*
Characteristic functions; applications of uniqueness and continuity theorems; central limit theorem. Other limit theorems; three series theorem, strong law of large numbers. Poisson process and introduction to Markov processes. Random walks, recurrent events, renewal theory, first passage problems. Introduction to infinitely divisible distributions.

**440(476)). Vector Analysis.** *Prerequisite: Math. 214 or 216.* I. *(2).*
The formal processes of vector analysis with applications to mechanics and geometry. Students cannot receive credit for both Math. 440 and 450.

**447. Modern Operational Mathematics.** *Prerequisite: preceded by or concurrently with Math. 450 or 451.* I and II. *(2).*
Laplace transformation, with emphasis on its application to problems in ordinary and partial differential equations of engineering and physics; vibrations of simple mechanical systems, of bars and shafts, simple electric circuits, transient temperatures, and other problems.

**448(548). Operational Methods for Systems Analysis.** *Prerequisite: preferably Math. 403 or 404 and 450 or 451.* I and II. *(4).*
Introduction to complex variables. Fourier series and integrals. Laplace transforms, application to systems of linear differential equations; theory of weighting function, frequency response function, transfer function, stability criteria, including those of Hurwitz-Routh and Nyquist.

**450. Advanced Mathematics for Engineers.** *Prerequisite: Math. 214 or 216.* I and II. *(4).*
Topics in advanced calculus including infinite series, Fourier series, improper integrals, partial derivatives, directional derivatives, line integrals, Green's theorem, vector analysis. Students cannot receive credit for both Math. 450 and 451.

**451(551). Advanced Calculus.** *Prerequisite: Math. 214 or 216.* I and II. *(4).*
Continuity and differentiation properties of functions of one and several variables; the definite integral and improper definite integrals, surface integrals and line integrals, Stokes' and Green's theorem; infinite series. Students cannot receive credit for both Math. 450 and 451.

**463(461). Statistical Methods for Engineers I.** *Prerequisite: Math. 214 or 216.* I and II. *(3).*
Statistical methods of quality control, normal, binomial, and Poisson distributions; Shewhart control chart; sampling methods in scientific acceptance inspec-

tion. Math. 463 and 464 together form an introductory course especially designed for the needs of engineers in both experimental work and the flow of production. Students cannot receive credit for both Math. 463 and 465.

**464(462). Statistical Methods for Engineers II.** *Prerequisite: Math. 463 or 465.* I and II. *(3).*
Significance tests; tests valid for small samples; introduction to linear correlation; elementary design of experiments. Students cannot receive credit for both Math. 464 and 466.

**465(561). Introduction to Statistics I.** *Prerequisite: Math. 214 or 216.* I and II. *(3).*
Basic probability and statistical concepts; univariate theory; calculational methods, distribution functions; binomial, normal, and Poisson distributions. Introduction to sampling theory. This course should be followed by Math. 466. Students cannot receive credit for both Math. 463 and 465.

**466(562). Introduction to Statistics II.** *Prerequisite: Math. 465.* I and II. *(3).*
Significance tests and confidence limits for large samples; exact sampling theory, including derivation and the use of Student-Fisher t; variance ratio and $\chi^2$; correlation and regression; the bivariate normal distribution; introduction to multivariate analysis. Students cannot receive credit for both Math. 464 and 466.

**473. Introduction to Digital Computers.** *Prerequisite: Math. 214 or 216.* I and II. *(3).*
Characteristics and logic of general purpose high-speed digital computers; introduction to logical design. The concept of algorithm, language, and symbol manipulation as applied to computer instruction. Computational methods for linear systems, differential equations, linear programming, etc. Laboratory work in programming the IBM 7090 computer.

**474. Numerical Analysis.** *Prerequisite: Math. 403 or 404 and 513 or 515, and 473 or equivalent.* I. *(3).*
The mathematics used with high-speed electronic computing machines. Presents attacks on: integration of ordinary differential equations, solution of large-scale linear systems, determination of eigenvalues and eigenvectors, integration of partial differential equations, function evaluation; coding and solution of problems on IBM 7090 computer.

**513(415). Introduction to Matrices.** *Prerequisite: Math. 412 or permission of instructor.* I and II. *(3).*
Vector spaces; linear transformations and matrices, equivalence of matrices and forms, canonical forms; application to linear differential equations.

**517. Introduction to Linear Algebra and Its Application.** *Prerequisite: one course beyond calculus or permission of instructor.* I and II. *(3).*
Boolean algebra and elements of set theory; matrix operation; equivalence, congruence, and similarity of matrices and forms; emphasis on applications. Intended primarily for students in engineering and social sciences.

**518. Optimization in Linear Systems.** *Prerequisite: Math. 517 or permission of instructor.* II. *(3).*
Solution of linear equations; linear inequalities and convex geometry; linear programming; simplex method; two-person zero-sum games, n-person games. Emphasis on applications of these topics. Students in mathematics should elect Math. 627.

**540(475). Theory of Potential Function.** *Prerequisite: Math. 450 or 451.* II. *(3).*
Newtonian attraction, Newtonian and logarithmic potentials, equations of Laplace and Poisson, harmonic functions, principle of Dirichlet, problems of Dirichlet and Neumann, and Green's function.

**552(452). Fourier Series and Applications.** *Prerequisite: Math. 450 or 451.* I and II. *(3).*
Orthogonal functions, Fourier series, Bessel functions, Legendre polynomials, and their application to boundary value problems in mathematical physics.

**554. Advanced Mathematics for Engineers II.** *Prerequisite: Math. 450.* II. *(4). Not open to students with credit for Math. 552 or 555.*
Topics in advanced calculus including functions of a complex variable, Fourier series and orthogonal functions, applications to boundary value problems.

**555(455). Introduction to Functions of a Complex Variable with Applications.** *Prerequisite: Math 450 or 451.* I and II. *(3).*
Complex numbers; limit, continuity; derivative; conformal representation; integration; Cauchy theorems; power series; singularities; applications to engineering and mathematical physics.

**557. Intermediate Course in Differential Equations.** *Prerequisite: Math. 450 or 451.* I and II. *(3).*
Linear equations of the second order; solution by power series; Riccati equations; extensive treatment of the hypergeometric equation; solutions of the equations of Bessel, Hermite, Legendre, and Laguerre.

**560(570). Theory of Survey Sampling.** *Prerequisite: Math. 465, 466, or permission of instructor.* I. *(3).*
The mathematical theory of the principal sampling methods used in social and economic surveys. Simple random sampling, stratified sampling, ratio and regression estimates, systematic sampling, subsampling and double sampling, cost functions and choice of optimum sample designs, estimational procedures.

**565(566). Least Squares and the Analysis of Variance.** *Prerequisite: Math. 466.* I. *(3).*
Geometry and statistics of linear hypotheses. Geometrical aids to least squares computation: illustrated by multiple regression, escalator methods, analysis of variance in various simple layouts (blocks, latin squares, factorial layouts), missing and extra observations, the analysis of covariance, and confounding. Related statistical situations; components of variance, split plots; randomized layouts; transformation of variables.

**566(569). Design of Experiments.** *Prerequisite: Math. 565.* II. *(3).*
The goals and devices of design with special reference to layouts and the analysis of covariance. The main combinatorial layouts, their uses and limitations. Sequential aspects of design, especially in the search for conditions of maximal yield; optimal allocation of observations; design considerations remote from layouts; and parallels with the theory of sampling.

**573(Com. Sci. 573). Automatic Programming.** *Prerequisite: Math. 473.* II. *(3).*
Topics in automatic programming of digital computers, including the structure of compilers and assemblers, the use of macroinstructions, the structure and use of executive systems, list storage, threaded lists, and automatic programming languages.

**654(778). Mathematics of Relativity.** II. *(3).*
Special relativity, general relativity, theories of the universe, unified field theories.

**749. Methods of Partial Differential Equations.** *Prerequisite: Math. 447, 552, and 555.* I and II. *(3).*
Theory and application of the solution of boundary value problems in the partial differential equations of engineering and physics by various methods; orthogonal functions, Laplace transformation, other transformation methods. Green's functions.

**751(750). Methods of Mathematical Physics I.** *Prerequisite: Math. 450, 552, and 555.* I. *(3).*
Regular integral equations, Sturm-Liouville systems. Asymptotic developments by saddle point and stationary phase methods. First-order partial differential equations.

**752(751). Methods of Mathematical Physics II.** *Prerequisite: Math. 751 or permission of instructor.* II. *(3).*
Classification of partial differential equations, representation theorems. Selected topics, such as direct methods and singular differential and integral equations.

**754. Advanced Partial Differential Equations.** *Prerequisite: Math. 701 or permission of instructor.* I. *(3).*
Modern developments in the theory of partial differential equations.

**755. Direct Methods in the Calculus of Variations.** *Prerequisite: Math. 450 and 552 or equivalent.* II. *(3).*
The method of steepest descent in relaxation theory; Dirichlet and Raleigh-Ritz principles and their application to Sturm-Liouville systems and partial differential equations.

**757. Special Functions in Classical Analysis.** *Prerequisite: permission of instructor.* II. *(3).*
Gamma, Bessel, Legendre, hypergeometric, and elliptic functions as treated in Whittaker and Watson's *Modern Analysis.* Generalized hypergeometric functions. Hermite and Laguerre polynomials.

**758. Ordinary Differential Equations.** *Prerequisite: Math. 602.* I. *(3).*
Existence theorems, linear systems, Sturm-Liouville theory.

**759. Topics in Ordinary Differential Equations.** *Prerequisite: Math. 758.* II. *(3).*
Modern developments in theory of ordinary differential equations.

**773. Advanced Numerical Analysis.** *Prerequisite: Math. 474 or permission of instructor.* II. *(3).*
Truncation, round-off and propagation error analysis for the solution of linear and nonlinear functional equations using a large hyphen-scale digital computer. Solution of partial differential equations by numerical techniques. Laboratory work in solution of one or more of such problems using the IBM 7090 computer.

## MECHANICAL ENGINEERING

**251. Manufacturing Processes I.** *Prerequisite: Chem.-Met. Eng. 250 and preceded or accompanied by Eng. Mech. 210 or Eng. Mech. 310.* I and II. *(3).*
Fundamentals of manufacturing processes. Effect of the process on surface condition, residual stresses, strain hardening, wear, and failure. Influence of the mechanical properties of materials on the process. Material selection for processing and design. Two recitations and one three-hour laboratory.

**252. Engineering Materials and Manufacturing Processes.** *Prerequisite: Chem.-Met. Eng. 250.* I and II. *(2).*
Correlation of the structure of metals with their mechanical properties; control of mechanical properties by modifying the microstructure; mechanical properties of commonly used metals; failure by corrosion; relations between mechanical properties and the manufacturing processes of casting, welding, plastic working, machining, and heat-treating. One lecture, one problem period, and two hours of laboratory.

**324. Fundamentals of Fluid Machinery.** *Prerequisite: Mech. Eng. 335 and Eng. Mech. 324.* I and II. *(4).*
Review of fundamental laws of fluid mechanics. Control volume analyses. One-dimensional compressible flow theory. Basic principles of turbo-machines. Compressor, turbine, and pump analyses. Three lectures and one three-hour laboratory.

**331. Classical and Statistical Thermodynamics.** *Prerequisite: Physics 145 and Math. 215.* I and II. *(4).*
Basic thermodynamics, first law, second law, properties of a pure substance, ideal gases and gaseous mixtures, application to heat-power machinery. Introduction to statistical thermodynamics and evaluation of thermodynamic properties. Not open to mechanical engineering students.

**333. Thermodynamics and Heat Transfer.** *Prerequisite: Physics 145 and Math. 215.* I and II. *(4).*
Basic thermodynamics, first law, second law, properties of a pure substance, ideal gases, and gaseous mixtures, application to heat-power machinery. Study of mechanism of heat-transfer processes. Conduction, thermal radiation, and convective processes. Not open to mechanical engineering students.

**335. Thermodynamics I.** *Prerequisite: Physics 145 and Math. 116.* I and II. *(3).*
Basic course in engineering thermodynamics. First law, second law, properties of a pure substance, ideal gases, mixtures of ideal gases and vapors, availability.

**336. Thermodynamics II.** *Prerequisite: Mech. Eng. 335 and Math. 216 and 273 or equivalent.* I and II. *(4).*
Continuation of Mech. Eng. 335. Power and refrigeration cycles; general thermodynamic relations, equations of state, and compressibility factors; chemical reactions; combustion; gaseous dissociation. Three one-hour lectures and one three-hour laboratory.

**337. Mechanical Engineering Laboratory.** *Prerequisite: preceded or accompanied by Mech. Eng. 335.* I and II. *(2).*
Demonstration and application of basic principles in various areas of mechanical engineering; instrumentation and the reliability of measurements; behavior

and nature of typical machinery and equipment. One four-hour period. Not open to mechanical engineering students.

**340. Dynamics of Mechanical Systems.** *Prerequisite: Eng. Mech. 343.* I and II. *(4).*
The principles of kinematics and dynamics applied to the analysis of mechanical systems. Transient and steady-state vibrations of simple mechanical systems. Three one-hour periods and one three-hour laboratory.

**343. Mechanical Design.** *Prerequisite: Eng. Mech. 343, 210 or 310. Not open to mechanical engineering students.* I and II. *(3).*
Application of the fundamentals of engineering science to mechanical design and analysis. Dynamic force analysis. Transient and steady state vibrations in simple mechanical systems. Combined stresses, fatigue, failure theories. Analysis and design of representative mechanical components and systems.

**362. Mechanical Design I.** *Prerequisite: Eng. Mech. 210 or 310 and preceded or accompanied by Mech. Eng. 251 or 381.* I and II. *(3).*
Introduction to the design process; morphology of design, creativity, optimization. Conceptual problems in mechanical design. Application of the fundamentals of engineering mechanics, materials, and manufacturing to the analysis and design of mechanical elements and systems.

**381. Manufacturing Processes II.** *Prerequisite: Mech. Eng. 251.* I and II. *(3).*
A study of machining, welding, and plastic forming of materials; analysis of forces, energy requirements, and temperature effects; design specifications economically obtainable in terms of dimensional accuracy, surface finish, and material properties; functional characteristics of equipment. Two recitations and one three-hour laboratory.

**398. Heating and Ventilating.** I and II. *(3).*
Theory, design, and construction of warm-air, steam, hot-water, and fan-heating systems; air conditioning and temperature control. Lectures, recitations. For architects only.

**408. Experimental Research in Mechanical Engineering.** *Prerequisite: senior standing and permission of instructor.* I and II. *(3).* Not for graduate credit.
Individual or group experimental research in a field of interest to the student under the direction of a member of the Mechanical Engineering Department. Topics may be selected from a list offered each semester including such areas as air conditioning, automotive engineering, fluids, heating, heat transfer, machine design, materials, processing, thermodynamics. The student will submit a report. Two four-hour laboratories per week. Time to be arranged.

**417. Plastic Forming of Metals I.** *Prerequisite: Mech. Eng. 251 and Math. 403 or 404.* I. *(3).*
Plastic deformation of metals with respect to their mechanical properties and metallurgical characteristics. Introduction to Cartesian tensors; analysis of stress, strain, and displacement; elastic stress-strain relations; yielding criteria; theory of dislocation and slip mechanism; plastic stress-strain relations, theory and experimental data; temperature and strain-rate effect; work of deformation; slip line fields.

**421. Dynamics and Thermodynamics of Compressible Flow.** *Prerequisite: Mech. Eng. 336 and 371.* I and II. *(3).*
One dimensional, compressible flow involving area change, normal shock,

friction, heat transfer. Two dimensional linearized, supersonic flow. Method of characteristics. Oblique shocks.

**422. Design Theory and Fluid Machinery.** *Prerequisite: Mech. Eng. 324.* I. *(3).*
Advanced development of the laws of thermodynamics, laws of motion and flow of fluids as applied to the design theory of axial- and radial-flow turbomachinery.

**432. Combustion.** *Prerequisite: Mech. Eng. 336, preceded or accompanied by Mech. Eng. 371 or equivalent.* II. *(3).*
Introduction to combustion processes, reaction kinetics, ignition and flame propagation. Combustion of sprays. Detonation, temperature, and radiation. Spectrographic analysis. Optical methods for combustion studies. Otto, diesel, gas turbine, and rocket combustion.

**437. Applied Energy Conversion.** *Prerequisite: Mech. Eng. 336 or equivalent.* II. *(3).*
Economic conversion of natural energy in stationary power plants. Major topics treated: combustion practice, steam generation, steam turbines, diesel engine power plants, hydraulic power plants, gas turbines, nuclear energy power plant economics, load curves, energy rates. Selected power plant problems are assigned.

**439(Chem.-Met. Eng. 439). Combustion and Air Pollution Control.** *Prerequisite: permission of instructor.* II. *(3).*
Fundamentals of combustion as related to furnaces, internal combustion engines and process plants, emphasizing formation and control of gaseous and particulate air contaminants.

**460. Mechanical Design IIa.** *Prerequisite: Mech. Eng. 340 and 362.* I and II. *(4).*
Continuation of the study of mechanical elements and systems. Design project with emphasis on the structure and dynamics of a mechanical system, including synthesis analysis, critique, layout and report. Two lectures and one two-hour design period.

**461. Automatic Control.** *Prerequisite: Math. 403 or 404, Mech. Eng. 340, Elec. Eng. 442.* I. *(3).*
Analysis of linear feed-back control with emphasis on mechanical systems. Transient and steady-state frequency response. Stability criteria. Systems performance compensation methods. Analysis of hydraulic, pneumatic, and inertial guidance components and systems. Introduction to nonlinear systems.

**462. Mechanical Design IIb.** *Prerequisite: Mech. Eng. 324, 336, 362, preceded or accompanied by Mech. Eng. 471.* I and II. *(4).*
Continuation of the study of mechanical elements and systems. Design project with emphasis on the thermal and fluid aspects of mechanical systems, including synthesis, analysis, critique, layout, and report. Two lectures and one two-hour design period.

**463. Wear Considerations in Design.** *Prerequisite: Mech. Eng. 343 or 362.* II. *(3).*
Design of machine members to avoid surface damage due to wear, pitting, scoring, frettage, and cavitation. Application to the design of press-fitted, keyed, and bolted assemblies; bearings, gears, cams, pumps, and liners.

**465. Mechanical Analysis Laboratory.** *Prerequisite: Mech. Eng. 340.* I and II. *(3).*
Laboratory use of instrumentation to measure forces, stresses, displacement, pressure, etc., in mechanical devices; use of transducers, display and recording devices, and of the analog computer for experimental analysis; short experiments

plus squad projects; lectures, laboratory, brief reports. Two three-hour periods per week.

**467. Lubrication and Bearing Analysis.** *Prerequisite: Mech. Eng. 362.* II. *(3).*
Viscosity; hydrostatic and hydrodynamic analysis of journal and thrust bearings; lubrication of rolling surfaces; thin-film lubrication; bearing materials; methods of lubrication; bearing design.

**471. Heat Transfer I.** *Prerequisite: Mech. Eng. 335 and Eng. Mech. 324.* I and II. *(4).*
Study of the mechanisms of heat-transfer processes. Steady and transient conduction in solids, numerical and graphical methods; heat-exchanger design, performance and economics; thermal radiation; convective processes, turbulent and laminar flow, steady and transient diffusion, mass transfer between phases. Three one-hour lectures and one three-hour laboratory.

**480. Design of Manufacturing Equipment.** *Prerequisite: Mech. Eng. 362.* I. *(3).*
Specification, design, construction, and operation of production machines and allied tooling. Consideration of bearings, lubrication, motors, controls and materials. Hydraulic and electric control units and circuits.

**482. Manufacturing Engineering.** *Prerequisite: Mech. Eng. 381.* I and II. *(4).*
Application of fundamental principles to problems arising in manufacturing. Particular attention is devoted to planning operations, designing special equipment, statistical quality control, cost analysis and reduction, and similar functions which engineers perform in connection with manufacturing. Two lectures and two three-hour laboratories.

**484. Gas Welding Processes.** *Prerequisite: Mech. Eng. 251 or 252 or permission of instructor.* I and II. *(2).*
Principles and applications in gas welding, brazing, flame cutting and metallizing. Welding metallurgy, stress analysis, heat treatment, and inspection techniques. Equipment, plant layout, supervision, certification, production procedures, cost analysis, and safety practices. One-hour lecture and a three-hour laboratory. Graduate credit not allowed for mechanical and industrial engineering students.

**485. Electric Welding Processes.** *Prerequisite: Mech. Eng. 251 or 252 or permission of instructor.* I and II. *(2).*
Electric arc, inert arc, automatic arc, and resistance welding techniques and applications. Welding metallurgy, stress analysis, micro-preparations and examinations. Testing and inspection of weldments. Welding of aluminum and high-temperature alloys. Introduction of research problems. One-hour lecture and a three-hour laboratory. Graduate credit not allowed for mechanical and industrial engineering students.

**486. Manufacturing Considerations in Design.** *Prerequisite: Mech. Eng. 343 or 362.* II. *(3).*
Correlation between functional specifications and process capabilities. Study of tolerances on basis of fabricability. Case studies in process engineering, including standards application. Problems in redesign for producibility.

**487. Welding.** *Prerequisite: Mech. Eng. 381.* I. *(3).*
Study of mechanism of surface bonding, welding metallurgy, effect of rate of heat input on resulting micro-structures, residual stresses and distortion, economics and capabilities of the various processes.

**488. Machinability Theory.** *Prerequisite: Mech. Eng. 340 and 381.* I. *(3).*
Metal cutting theory and its relation to practical problems. Basic theories on mechanics of the shear zone, flow stress, friction, energy conversion, temperature, vibration, and wear mechanisms. Study of current literature on problems concerning size control, residual stresses, surface finish, and tool life.

**491. Heating and Air Conditioning.** *Prerequisite: Mech. Eng. 335.* II. *(3).*
Theory and design of warm-air, steam, hot-water, and radiant-heating systems; moisture and temperature control; cooling and air conditioning; fans, air flow; fume exhaust systems.

**492. Design of Heating and Air-Conditioning Systems.** *Prerequisite: Mech. Eng. 491.* II. *(3).*
The student is given the usual data furnished the heating and ventilating engineer. He then makes a layout of piping, ducts, and auxiliary apparatus, with computation for the size of principal equipment. Two four-hour periods.

**493. Gas Turbine Engines.** *Prerequisite: Mech. Eng. 336.* I. *(3).*
Design point analysis of gas turbine powerplants, performance of basic cycle arrangements, aircraft jet propulsion; compressor, turbine and combustor characteristics.

**495. Analysis and Design of Rocket Engines.** *Prerequisite: Mech. Eng. 336, preceded or accompanied by Mech. Eng. 324 and 471.* II. *(3).*
Application of gas dynamics and heat transfer to rocket engines; propellant thermo-chemistry, feed-system hydraulics, design of liquid and solid propellant rockets; advanced rocket propulsion systems.

**496. Internal-Combustion Engines.** *Prerequisite: Mech. Eng. 336.* I and II. *(3).*
Comparison of characteristics and performance of the several forms of internal-combustion engines including the Otto and Diesel types of piston engines, gas turbines, ramjets, and rockets; thermodynamics of cycles, combustion, ignition, fuel metering and injection, supercharging, and compounded engines.

**497. Automotive Laboratory.** *Prerequisite: preceded or accompanied by Mech. Eng. 496.* I and II. *(3).*
Experimental study of automobile and aircraft engines, including horsepower, fuel economy, thermal efficiency, mechanical efficiency, energy balance, indicator cards, carburetion, compression ratio, electrical systems, and road tests for car performance. Laboratory and reports. One four-hour laboratory.

**498. Automotive Engineering.** *Prerequisite: Mech. Eng. 362.* I. *(3).*
Design of automobile and truck suspensions, steering, brakes, drive lines, axles, frames, bodies, and cabs. Acceleration, gradability, stability, and ride comfort. Power-weight ratio. Engine-transmission compatibility. Problems of performance and economy.

**501 to 513, inclusive.**
These courses are offered at University of Michigan Centers outside of Ann Arbor. For course titles, prerequisites, and credits see the *Announcement* of the Horace H. Rackham School of Graduate Studies. For complete descriptions, see the *Announcement* of the University of Michigan Dearborn Center. These courses will also be scheduled in the Extension Service bulletins. They are approximately equivalent to Ann Arbor campus courses as follows: Mech. Eng. 501 and 502 to Mech. Eng. 540; Mech. Eng. 503 and 504 to 556; Mech. Eng. 505 and 506 to 535; Mech. Eng. 507 and 508 to Mech. Eng. 571; Mech. Eng. 509 and

510 to Mech. Eng. 524; Mech. Eng. 511 and 512 to Mech. Eng. 550. Credit will not be granted to students who have completed the corresponding courses.

**516. Special Topics in Mechanical Engineering.** *Prerequisite: senior standing and permission of instructor. (To be arranged).*
Selected topics pertinent to mechanical engineering.

**517. Plastic Forming of Metals II.** *Prerequisite: Mech. Eng. 417 or equivalent.* II. *(3).*
Application of the principles of plasticity to the forming processes. Analysis of extrusion of ideal plastic materials and strain hardening materials. Analysis of wire drawing, rolling, forging, and deep drawing. Application of slip lines to extrusion and forging. Bendability of metals.

**524. Fluid Mechanics II.** *Prerequisite: Eng. Mech. 324 and Math. 450 or 451.* I. *(3).*
Dimensional analysis, basic concepts, equations of continuity, stream lines and stream surfaces, vorticity and circulation; equations of motion; irrotational flow theory, mathematical techniques for solution of flow equations; complex variables, conformal mapping with applications to solution of two-dimensional flow problems.

**531. Statistical Thermodynamics.** *Prerequisite: Mech. Eng. 331 or 336, Math. 403 or 404.* II. *(3).*
Introduction to statistical methods for evaluating thermodynamic and transport properties. Elements of quantum mechanics, statistical mechanics, and kinetic theory, as applied to engineering thermodynamics.

**535. Thermodynamics III.** *Prerequisite: Mech. Eng. 336.* I and II. *(3).*
Definitions and scope of thermodynamics; first and second laws, Maxwell's relations, Clapeyron relation, equation of state, thermodynamics of chemical reactions, availability.

**539. Cryogenics and Refrigeration.** *Prerequisite: Mech. Eng. 336 and preceded or accompanied by Mech. Eng. 471.* II. *(3).*
Theoretical and design aspects of producing temperatures below ambient. Vapor compression systems; absorption systems; liquefaction and separation of air; liquefaction and properties of cryogenic fluids; insulation problems; and unique phenomena at extremely low temperatures.

**540. Mechanical Vibrations.** *Prerequisite: Math. 404, Mech. Eng. 340 or 343.* I and II. *(3).*
A study of shock and impact on mechanical systems and machines. Analysis, reduction, and isolation of vibrations. Mounting of machines and equipment; critical speeds and torsional vibrations of rotors; vibration absorbers and dampers. Solution of steady-state and transient vibration problems by mathematical, graphical, and analogue solutions.

**541. Synthesis of Mechanisms.** *Prerequisite: Math. 216 and Mech. Eng. 340 or 343.* I. *(3).*
Vector and complex function analysis of mechanisms with emphasis on space mechanisms. A survey of various methods used in synthesis of linkages. Kinematically equivalent linkages. Analysis and design of cams. Mechanical computing mechanisms. Mechanism trains.

**550. Mechanical Behavior of Solids I.** *Prerequisite: Mech. Eng. 381 and Chem.-Met. Eng. 270.* I. *(3).*

Atomic mechanisms involved in plastic deformation and fracture of solids. Quantum theory and atomic bonding forces. Behavior of single crystals and polycrystalline solids. Dislocation theories and observations. Elastic and plastic stress-strain relationships. Fundamentals of brittle and ductile fracture.

**551. Mechanical Behavior of Solids II.** *Prerequisite: Mech. Eng. 550.* II. *(3).*
Mechanisms of fatigue in solids. Internal fraction. Surface phenomena. Effects of extreme environments on the mechanical behavior of solids. Radiation damage.

**556. Stress Considerations in Design.** *Prerequisite: Mech. Eng. 343 or 362.* I and II. *(3).*
Treatment of stress and strength aspects of machine design. Analytic and experimental determination of stresses in machine members. Evaluation of strength under steady and fatigue loadings. Post-yield behavior, residual stresses, temperature and corrosion effects.

**563. Instrumentation and Control.** *Prerequisite: a degree in engineering or permission of instructor.* II. *(3).*
Automatic controls; fluid metering; measurements of temperature, humidity, pressure, displacement, strain, speed, sound, etc.

**567. Reliability Consideration in Design.** *Prerequisite: Mech. Eng. 343 or 362 or equivalent.* I. *(3).*
Design of machines and machine members to insure reliability in field and service. The concept of value, system, and system effectiveness. Design reliability versus quality control. Techniques for predicting reliability. Design of experiments. The feedback approach to reliability. Statistical tolerances. Failure analysis.

**571. Heat Transfer II.** *Prerequisite: Mech. Eng. 471 and Math. 403 or 404.* I and II. *(3).*
Conduction heat transfer in steady and transient state, including heat sources. Analytical, numerical, graphical, and analog methods of solution for steady and fluctuating boundary conditions. Thermal stresses. Dynamics of thermal instrumentation and heat exchangers.

**588. Machinability Research.** *Prerequisite: Mech. Eng. 488.* II. *(4).*
Lecture and laboratory on metal-cutting research techniques. Design of dynamometers, temperature measuring methods, analysis of residual stresses, vibrations, cutting forces, chip formation, and tool wear. Two lectures and two three-hour laboratory periods per week.

**594. Internal-Combustion Engines II.** *Prerequisite: Mech. Eng. 496.* II. *(3).*
Balance and vibration; advanced thermodynamic analysis of engines; chemical equilibrium and kinetics of combustion; theory and control of detonation; combustion analysis; principles underlying recent advances in engines.

**595. Automotive Engineering Research.** *Prerequisite: Mech. Eng. 497 and permission of instructor.* I and II. *(3).*
Advanced experimental and research work. Laboratory and reports.

**600. Study or Research in Selected Mechanical Engineering Topics.** *Prerequisite: graduate standing; permission of instructor who will guide the work should be obtained before classification.* I and II. *(Credit to be arranged).*
Individual or group study, design, or laboratory research in a field of interest to the student. Topics may be chosen from any of the areas of mechanical

engineering. The student will submit a report on his project and give an oral presentation to a panel of faculty members at the close of the semester.

**607. Mechanical Engineering Problems.** *Prerequisite: preceded by Math. 403 or 404.* I and II. *(3).*
Analysis of problems in mechanical vibrations, resonance and critical speeds, fluid-flow, thermodynamics, heat-flow, weight distribution, and strength of materials, processing, and materials.

**625. Introduction to Viscous Flow Theory.** *Prerequisite: Mech. Eng. 524 or Eng. Mech. 422 or permission of instructor.* II. *(3).*
Fundamental concepts, exact and approximate solutions of the Navier-Stokes equations; exact and approximate solutions of equations for two- and three-dimensional laminar boundary layers; similarity solutions; momentum-integral methods; series solutions. Applications to flow in turbomachinery.

**672. Heat Transfer III.** *Prerequisite: Mech. Eng. 471.* II. *(3).*
Study of the nature of convective processes involving the transfer of heat, mass and momentum. Boundary layer theory. Analogy between heat and momentum transfer. Condensation and boiling phenomena, two-phase flow. Natural convective processes, steady and transient diffusion, mass transfer between phases.

**673. Heat Transfer IV.** *Prerequisite: Math. 403 and Mech. Eng. 471.* I. *(3).*
Thermal radiation process. Physics of monocromatic and total radiation. Emission and absorption. Exchange factors for black and gray surfaces and enclosures. Radiant exchange involving absorbing and emitting media, including gases and flames. Properties of solar radiation and thermal transfer in space.

**700. Professional Problems.** I and II. *(9).*
Professional degree candidate only. Student selects a problem in research, analysis, or design in any field of mechanical engineering and submits a written proposal to the Graduate Committee for approval before enrolling in course. Letter from staff member who will direct work must accompany proposal.

**772. Heat Transfer V.** *Prerequisite: Mech. Eng. 571 and 672, Math. 552, or equivalents.* I or II. *(3).*
Generalized methods of analysis applied to advanced problems in heat and mass transfer including the influence of magnetic field phenomena; transient processes in distributed fluid-solid systems having mixed boundary conditions; systems undergoing ablation and melting, transient thermal stresses.

**820. Fluids Machinery Seminar.** *Prerequisite: graduate standing and permission of instructor. (To be arranged).* I or II. Offered upon sufficient demand.
Reports and discussions on library study and laboratory research in selected topics.

**835. Seminar in Thermodynamics.** *Prerequisite: Mech. Eng. 531 and 535 or permission of instructor.* I or II. *(3).*
Thermodynamic analysis of rectification, low-temperature phenomena equilibrium, metastable states, and compressible flow.

**838. Heat-Power Seminar.** *Prerequisite: graduate standing and permission of instructor. (To be arranged).* Offered upon sufficient demand.
Reports and discussions on library study and laboratory research in selected topics.

## METEOROLOGY AND OCEANOGRAPHY

NOTE—*Extra work is required for graduate credit in Meteorology and Oceanography 432, 440, 441, 445, 452, and 470.*

**202(Geog. 202). Weather, Climate, and Life.** I and II. *(3).*
An elementary description of the atmosphere, its characteristics, and behavior; weather and climate as basic factors in life and civilization.

**404(Geog. 404). Introductory Meteorology—Weather.** *Prerequisite: preceded or accompanied by Math. 105 or equivalent. No credit allowed in a degree program in meteorology.* I and II. *(3).*
Wind and storm systems, cloud and precipitation, and other weather processes as revealed by meteorological research, with an elementary discussion of weather instruments and forecasting. Lectures, term paper, and field trips.

**405 (Geog. 405). Introductory Meteorology—Climate.** *Prerequisite: Meteor.-Ocean. 202 or 404. No credit allowed in a degree program in meteorology.* **II.** *(3).*
Climatic elements, controls, and regimes with a discussion of their distribution, classification, and fluctuation, and of the significance of climatic influences in the modern world. Lectures and term paper.

**408. Mathematical Meteorology for Engineers and Scientists.** *Prerequisite: Math. 403 or 404 and Physics 146.* I. *(3).*
Introduction to the basic thermodynamic, radiative, and dynamic processes in the atmosphere; physical analysis of wind and turbulence; cloud, precipitation, and evaporation physics; physics of the high atmosphere.

**412. Physical Climatology.** *Prerequisite: preceded or accompanied by Meteor.-Ocean. 408 or 432 or 445.* I. *(3).*
A survey of the general circulation of the atmosphere; the physical processes governing climate; solar radiation and the terrestrial heat balance; influence of large scale condensation and evaporation processes; the formal classification of climates according to zones and types; the application of climatic concepts.

**415. Statistical Methods in Meteorology I.** *Prerequisite: one year of calculus.* I. *(3).*
Distributions in time and space of meteorological elements; measures of central tendency and dispersion; distributions of scalar and vector quantities; introduction to statistical inference and significance tests; fiducial limits; regression analysis; trends and cycles; forecast verification. Lectures and laboratory exercises.

**422. Introductory Microclimatology.** II. *(3).*
The physical processes which govern microweather and microclimate; temperature, humidity, and wind near the ground in relation to height, time, soil, vegetation, and topography. Lectures and field experiments.

**432. Atmospheric Thermodynamics and Radiation.** *Prerequisite: Math. 214 and Physics 146 or equivalent.* I. *(3).*
Composition of the atmosphere; atmospheric statics; thermodynamic diagrams; solar and terrestrial radiation; the heat balance of the earth. Lectures and problems.

**440. Principles of Weather Analysis.** *Prerequisite: preceded or accompanied by Meteor.-Ocean. 408 or 432 or 445.* I. *(3).*

Air mass analysis, representative and conservative properties; detailed three-dimensional structure of fronts and pressure systems; principles of construction of prognostic pressure charts; procedures for forecasting the weather elements; the verification of weather forecasts. Lectures and problems.

**441. Laboratory in Weather Analysis I.** *Prerequisite: preceded or accompanied by Meteor.-Ocean. 440.* I. *(3).*
Construction of meteorological charts from current and past weather data. Analytical codes; measurement of geostrophic and gradient winds; graphical determination of thickness patterns; jet-stream analysis; principles of prognosis from thermodynamic diagrams, isallobaric and isobaric analyses.

**443(Zool. 443, Fish. 443). Limnology and Oceanography.** *Prerequisite: permission of instructor.* I. *(3).*
Lectures on the environmental conditions which affect the biotic assemblages in the world's aquatic habitats.

**444(Zool. 444, Fish. 444). Investigations in Limnology and Oceanography.** *Prerequisite: permission of instructor.* I. *(3).*
Discussion, laboratory, and field work dealing with interpretation of the interaction of environmental factors in natural waters. Emphasis on local habitats.

**445. Dynamic Meteorology.** *Prerequisite: Math. 214 and Physics 146 or equivalent.* II. *(3).*
The stratification of the atmosphere; the hydrostatic equation; virtual temperature; the equations of motion; barotropy and baroclinicity; stream function; circulation and vorticity; local change of pressure; atmospheric turbulence; the jet stream; weather prediction by high-speed computing methods.

**452. Physical Meteorology.** *Prerequisite: Meteor.-Ocean. 408 or 432 or 440.* II. *(3).*
Cloud and precipitation physics; aircraft icing; radar meteorology; atmospheric electricity; atmospheric optics and visibility. Lectures and problems.

**462. Meteorological Instrumentation.** *Prerequisite: Meteor.-Ocean. 408 or 432 or 445 or equivalent.* I. *(3).*
Principles of meteorological instruments; methods of measurement of pressure, temperature, humidity, precipitation, evaporation, and wind; analysis of response characteristics; introduction to the design of single instruments and of instrument systems. Lectures, laboratory, and field trips.

**470. Applied Meteorology.** *Prerequisite: Meteor.-Ocean. 404 or 408 or equivalent.* II. *(2).*
Topics in applied meteorology, selected in accordance with the requirements of the class. Representative topics; meteorological aspects of air polution; atmospheric phases of the hydrologic cycle; wind and precipitation loading of structures. Lectures and problems.

**472. Hydrometeorological Design.** *Prerequisite: Math. 214 and Physics 146.* I. *(2).*
Selected topics relating meteorology and hydrology; typical problems of wind and waves, intensity and persistence of drought, snow melt and stream runoff, cloud seeding. Recitation and laboratory.

**475. Meteorological Analysis and Design Criteria.** *Prerequisite: Math. 214 and Physics 146.* II. *(2).*
Statistical and graphical techniques used in meteorology; binomial, Poisson, and normal distributions; correlation and regression; statistical tests of signifi-

cance; construction of nomographs. Basic concepts applied to air pollution, microwave transmission, and other fields. Recitation, laboratory, and problems.

**500. Meteorology for Teachers.** Not open to engineering students. *(2-3).*
Lectures and discussions on elementary meteorology, combined with workshop on problems of introducing meteorology into individual school programs; survey of material sources, demonstration methods, laboratory and field exercises and equipment design. For science teachers of all levels.

**531(Zool. 531). Advanced Oceanography.** *Prerequisite: permission of instructor.* II. *(4).*
Lectures and outside study of the physical, chemical, and geological factors in marine environment. Designed to bridge from simple principles to the status of present research. Waves, tides, seiches, ocean basin tectonics comprise the framework of the course.

**541. Laboratory in Weather Analysis II.** *Prerequisite: Meteor.-Ocean. 441.* II. *(3).*
Applications of prognostic methods from analyses of vorticity patterns; trajectories and fallout computations; streamlines and isogons as used in tropical analyses; vertical cross sections; vertical motion calculation; introductory demonstration of numerical weather prediction; long waves and hemispheric weather.

**566. Micrometeorological Instrumentation.** *Prerequisite: permission of instructor.* II. *(3).*
Analysis of requirements for instrumentation; measurement of radiation, temperature, humidity, and wind velocity near the ground and of their fluctuations and vertical gradients; exposure and ventilation of instruments in relation to soil, terrain, vegetation, and water surfaces. Lectures, laboratory, and field studies.

**573. Air Pollution Meteorology.** *Prerequisite: permission of instructor.* I. *(3).*
Weather and motion systems of the atmosphere; topographic influences on winds; atmospheric stability and inversions; atmospheric diffusion; natural cleansing processes; meteorological factors in plant location, design and operation.

**605. Current Topics in Meteorology.** *Prerequisite: permission of instructor.* I. *(3).*
Basic concepts of the energetics of the atmosphere; internal, potential and kinetic energy; available potential energy; present knowledge regarding the distribution of energy in the atmosphere; energy transformation; energy generations and energy dissipation from an observational and theoretical point of view.

**615. Statistical Methods in Meteorology II.** *Prerequisite: permission of instructor.* II. *(3).*
Homogeneity of climatometric series; forecast economics; stochastic prediction; multiple regression; statistical screening; orthogonal representations; harmonic analysis; filtering and rectification of time series; power spectra; extreme values. Lectures and the solution of problems on desk calculators and on the IBM 7090.

**622. Micrometeorology.** *Prerequisite: Meteor.-Ocean. 432 or 445 or permission of instructor.* II. *(3).*
Physical processes in the atmosphere near the ground; laminar and turbulent flow; transfer of heat, mass and momentum; eddy diffusion; evaporation from natural surfaces. Lectures and problems.

**675(Zool. 675). Current Problems in Limnology and Oceanography.** *Prerequisite: permission of instructor.* I. *(2).*
Discussion of current concepts and problems varying in content and designed to

put the student in touch with recent advances and with areas of uncertainty presently under investigation. Designed to rotate the student through dynamics, biology, sedimentation, and other major areas of the field. Student expected to register more than one year.

**676(Zool. 676). Current Problems in Limnology and Oceanography.** *Prerequisite: permission of instructor.* II. *(2).*
Discussion of current concepts and problems varying in content and designed to put the student in touch with recent advances and with areas of uncertainty presently under investigation. Designed to rotate the student through dynamics, biology, sedimentation, and other major areas of the field. Student expected to register more than one year.

**701. Special Problems in Atmospheric Science.** *Prerequisite: permission of instructor.* I and II. *(To be arranged).*
Supervised analysis of selected problems in various areas of meteorology and associated fields.

**804. Interdisciplinary Seminar on Atmospheric Sciences.** *Prerequisite: permission of instructor.* I and II. *(1-3).*
Reading, preparation of term papers, and seminar discussion of fundamental atmospheric properties and characteristics and their relation and interaction with other disciplines. Course credit assigned each student on registration.

**990. Meteorological Research.** *Prerequisite: permission of graduate adviser.* I and II. *(To be arranged).*
Assigned work in meteorological research; may include field measurements, analysis of data, development in physical or applied meteorology.

**994. Doctoral Thesis.** I and II. *(To be arranged).*

## NAVAL ARCHITECTURE AND MARINE ENGINEERING

**200. Introduction to Practice.** *Prerequisite: sophomore standing and Eng. Graphics 101 and 104.* I and II. *(2).*
Types of ships and propulsion systems, nomenclature, methods and materials of construction, shipyard and drawing-room practices. The lines of a vessel are faired, and drawings prepared for typical ship structures.

**201. Form Calculations and Static Stability I.** *Prerequisite: Nav. Arch. 200, Math. 215, and Eng. Mech. 208.* I and II. *(3).*
Methods of determining areas, volumes, centers of buoyancy, displacement, and wetted surface; the use of hydrostatic curves; trim; initial stability; stability in damaged condition; launching; and watertight subdivision.

**300. Form Calculations and Static Stability II.** *Prerequisite: Nav. Arch. 201 and Math. 273.* I and II. *(2).*
Programming of hydrostatic curves; other problems for digital and analog computers.

**310. Structural Design I.** *Prerequisite: Eng. Mech. 210 and Nav. Arch. 201.* I and II. *(3).*

Design of the ship's principal structure to meet general and local strength requirements. Analysis of framing, shell, decks, bulkheads, welding, and testing.

**330. Marine Propulsion Machinery.** *Prerequisite: Mech. Eng. 335 and preceded or accompanied by Eng. Mech. 324.* I. *(3).*
The principles of design and operation of the ship's boilers, turbines, and other major machinery items.

**331. Marine Auxiliary Machinery.** *Prerequisite: Nav. Arch. 330 or Mech. Eng. 336 and preceded or accompanied by Elec. Eng. 316.* II. *(3)*
The principles of design of piping systems; electrical distribution; engine-room and deck auxiliaries.

**400. Shipbuilding Contracts and Cost Estimating.** *Prerequisite: junior standing.* I. *(2).*
Principal features of ship specifications and contracts; methods and practices of cost estimating and production control of shipbuilding.

**401. Small Craft Design.** *Prerequisite: preceded or accompanied by Nav. Arch. 420.* II. *(2).*
Design of motorboats, sailboats, hydrofoils, and other small craft.

**402. Small Commercial Vessel Design.** *Prerequisite: preceded or accompanied by Nav. Arch. 420.* I. *(2).*
Design of small commercial craft such as fishing boats, tugs, towboats, barges, and coasters.

**410. Stress Analysis of Ship Structures.** *Prerequisite: Eng. Mech. 411.* I. *(2).*
Beams under action of axial and lateral loads, beams on elastic supports; analysis of bulkheads, plating supported by a grillage system of stiffeners; effective width of plating, closed frame analysis.

**420. Resistance, Propulsion, and Propellers.** *Prerequisite: Nav. Arch. 201 and Eng. Mech. 324.* I and II. *(5).*
Fundamentals of the resistance and propulsion of ships including the theory of model testing. Theory and practice of propeller design with reference to model propeller testing. Ship powering predictions and calculations. Four recitations and one three-hour laboratory.

**430. Design of Marine Power Plants I.** *Prerequisite: Nav. Arch. 331.* I and II. *(2).*
Preliminary heat balance and other problems encountered in marine power-plant design.

**440. Ship Dynamics.** *Prerequisite: Nav. Arch. 201, Eng. Mech. 343, and Math. 404.* I. *(2).*
The motion of ships at sea, rolling, pitching, sea-keeping qualities; steering and maneuvering.

**446. Theory of Ship Vibrations I.** *Prerequisite: Eng. Mech. 343 and Math. 214 or 216.* I. *(3).*
General outline of vibration theory; vibration of masts, longitudinal and torsional vibration of propulsion machinery; hull vibrations, vertical, lateral, longitudinal, and torsional; other selected problems.

**470. Ship Design I.** *Prerequisite: senior standing.* I and II. *(3).*
Preliminary design methods, general arrangements and outfitting of ships.

Given the owner's general requirements, the student blocks out initial design characteristics for the ship.

**471. Ship Design II.** *Prerequisite: Nav. Arch. 470 and accompanied by Nav. Arch. 472.* I and II. *(2).*
Basing his work on the design started in Nav. Arch. 470, the student prepares the preliminary design drawings and final calculations for the subject vessel.

**472. Structural Design II.** *Prerequisite: Nav. Arch. 310 and accompanied by Nav. Arch. 471.* I and II. *(2).*
Student develops the midship section for the vessel designed in Nav. Arch. 470 and Nav. Arch. 471 and makes freeboard, strength, and steel weight calculations.

**473. Design of Marine Power Plants II.** *Prerequisite: Nav. Arch. 430.* I and II. *(3).*
Design calculations to establish the heat balance of an approved machinery installation. Preliminary machinery arrangement and piping diagrams are prepared.

**510. Advanced Structural Design.** *Prerequisite: Nav. Arch. 410.* I and II. *(To be arranged).*

**511. Directed Research in Ship Structure.** *Prerequisite: Nav. Arch. 510.* I and II. *(To be arranged).*

**520. Advanced Ship Model Testing.** *Prerequisite: Nav. Arch 420.* I and II. *(2 to 3).*
Special problems in ship model testing will be investigated, varying with the student's interest.

**521. Research in Ship Hydrodynamics.** *Prerequisite: Nav. Arch. 520.* I and II. *(To be arranged).*

**522. Theory of Wave Resistance.** *Prerequisite: Eng. Mech. 422, Math. 552, accompanied by Math. 555.* II. *(3).*
Formulation of the inviscid potential flow problem for a surface vessel. Solution of the linearized boundary value problem for steady flow by Fourier analysis and by method of Greene's functions. Determination of wave resistance by pressure integral, energy, and momentum. Methods of evaluating the Michell integral.

**530. Theory of Ship Vibrations II.** *Prerequisite: Eng. Mech. 422, Nav. Arch. 446, Math. 450.* II. *(2).*
Hydrodynamic masses of vibrating ships. Calculation of natural frequencies of a ship's hull. Calculation of hull response to exciting forces. Vibratory forces produced by a propeller. Vibration of panels. Problems of hydroelasticity in ship design.

**540. Theory of Ship Motions.** *Prerequisite: Eng. Mech. 422, Nav. Arch. 440, Math. 450.* I. *(3).*
The general dynamic theory of a ship moving with six degrees of freedom with and without the exciting forces of surface waves. Coupled pitching and heaving, linear and nonlinear rolling. Motion stabilizers.

**571. Advanced Ship Drawing and Design.** I and II. *(To be arranged).*

**572. Economics of Ship Design and Operation.** *Prerequisite: Nav. Arch. 470.* II. *(2).*

Review of mathematics of finance, estimating ship construction and operating costs and income; interpretation of data; profitability; optimum design conditions; replacement; intangible factors.

**590. Advanced Reading and Seminar in Marine Engineering.** I and II. *(To be arranged).*

**591. Advanced Reading and Seminar in Naval Architecture.** I and II. *(To be arranged).*

**592. Thesis Research.** *Prerequisite: Nav. Arch. 470 or design course in Option 2 and Nav. Arch. 420.* I and II. *(3).*

**620. Advanced Propeller Theory and Cavitation.** *Prerequisite: Eng. Mech. 422 and Nav. Arch. 420.* I. *(2).*
Fundamentals of circulation theory of screw-propeller design; propeller cavitation; supercavitating propellers.

**630. Nuclear Ship Propulsion.** *Prerequisite: Nuc. Eng. 400 or 470 or equivalent.* I. *(3).*
A discussion of the basic problems encountered in the application of nuclear reactors to ships. Brief review of the nontechnical problems of nuclear merchant ship propulsion.

## NUCLEAR ENGINEERING

**400. Elements of Nuclear Engineering.** *Prerequisite: senior standing or permission of instructor.* I and II. (3).
A quantitative survey of nuclear engineering for those in fields other than nuclear engineering. Elementary nuclear physics, neutron mechanics, the nuclear reactor, radiation shielding, instrumentation and control, and nuclear powerplant systems are the principal topics surveyed.

**470. Introduction to Nuclear Engineering.** *Prerequisite: preceded or accompanied by Math. 450.* I, II, and S.S. *(3).*
Designed to give students a background in the aspects of atomic and nuclear physics prerequisite to an understanding of neutron processes. Discussion of Planck's constant and basic properties of the neutron.

**500. Special Topics in Nuclear Engineering I.** *Prerequisite: permission of instructor.* I and II. *(To be arranged).*
Selected topics offered at the senior-first year graduate level. The subject matter may change from semester to semester.

**520. Introduction to Thermonuclear Theory.** *Prerequisite: one intermediate course in electricity and magnetism.* II. *(3).*
Properties of thermonuclear plasmas from the standpoint of magneto-fluid mechanics. Typical parameters in a hypothetical thermonuclear reactor. Orbit theory; hydromagnetic equations of motion; generalized ohms law problems; energy principle for stability. Plasma waves; survey of experimental techniques applied to problems of plasma confinement and heating.

**550. Handling and Use of Radioactive Materials.** *Prerequisite: senior standing or permission of instructor.* I and II. *(3).*
Uses of nuclear radiation in industry and research. Procedures in the safe handling of radioactive materials, hazard evaluations, and design of radiation facilities. One-hour lecture, demonstrations, and experiments with high-level sources.

**560. Nuclear Radiation Detection and Measurement.** *Prerequisite: Nuc. Eng. 470, preceded or accompanied by a course in electronics.* I and II. *(3).*
Nuclear radiation detection methods and instrument systems in nuclear engineering; basic concepts of health physics and statistics; basic nuclear phenomena and the characteristics of nuclear radiations. Lectures and laboratory.

**570. Quantum Mechanics in Neutron-Nuclear Reactions.** *Prerequisite: Nuc. Eng. 470 and Math. 450.* I and II. *(3).*
An introduction to quantum mechanics with applications to nuclear science and nuclear engineering. Topics covered include the Schroedinger equation and neutron-wave equations, neutron absorption, neutron scattering, details of neutron-nuclear reactions, cross sections, the Breit Wigner formula, neutron diffraction, nuclear fission, transuranic elements, the deuteron problem, masers, and lasers.

**630. Nuclear Power-Plant Engineering.** *Prerequisite: preceded or accompanied by Nuc. Eng. 680, or preceded by Nuc. Eng. 400.* II. *(3).*
Application of reactor core theory, reactor control, fluid-flow, heat transfer, thermodynamics, stress and strain, and economic parameters to integrated nuclear power-plant designs. Examination of significant nuclear power-plant concepts and applications.

**631. Nuclear Power-Plant Laboratory.** *Prerequisite: preceded or accompanied by Nuc. Eng. 630, or permission of instructor.* I. *(1).*
The application of heat transfer, fluid-flow, thermodynamics, and the stresses of special importance to nuclear power-plant engineering. Techniques of research in these areas. An idea of the present state of the art. Lecture and laboratory.

**640. Application of the Analog Computer in Nuclear Engineering.** *Prerequisite: preceded or accompanied by Nuc. Eng. 680, or preceded by Nuc. Eng. 400.* I and II. *(2).*
Basic theory and principles of operation of the electronic analog computer. Practice in the operation of the computer. Solution of linear and nonlinear problems in nuclear engineering such as fission product buildup and decay, nuclear reactor kinetics and control. Lecture and laboratory.

**641. Nuclear Reactor Instrumentation and Control.** *Prerequisite: preceded or accompanied by Nuc. Eng. 680, or preceded by Nuc. Eng. 400.* II. *(3).*
Reactor kinetics, reactor stability studies; measurement of reactor power level and period; automatic control methods for thermal and fast reactors; temperature effects; accident studies; the use of analog computers in studying reactor dynamics; the loaded reactor.

**660. Nuclear Reactor Laboratory.** *Prerequisite: Nuc. Eng. 560, preceded or accompanied by Nuc. Eng. 680.* I, II, and S.S. *(4).*
Characteristics and operation of a nuclear reactor and the use of a reactor as a radiation source, using the one-megawatt Ford Nuclear Reactor in the Phoenix Memorial Laboratory. Lectures and laboratory.

**670. Interaction of Radiation and Matter.** *Prerequisite: Nuc. Eng. 570.* I and II. *(3).*
Classical and quantum-mechanical analysis of the processes by which radiation interacts with matter. Review of nuclear structure and properties. Nuclear models. Nuclei as sources of radiation. Interaction of electromagnetic radiation with matter. Interaction of charged particles with matter. Radiative collisions and theory of bremsstrahlung. Interaction of neutrons with matter. Interaction mechanisms and cross sections are developed.

**680. Reactor Theory I.** *Prerequisite: preceded or accompanied by Nuc. Eng. 570; Math. 448 or 554, or Phys. 451.* II. *(3).*
A study of the behavior of nuclear reactors based on the diffusion equation. Derivation of the one-speed diffusion equation, and its solution. Elementary theory of neutron slowing down in infinite media. Age theory. Criticality of bare, homogeneous reactors. Reflected reactors and group diffusion methods. Elementary theory of reactor kinetics, fission product poisoning, and control.

**690. Master's Project.** I, II, and S.S. *(1–6).*
Individual or group investigations in a particular field or on a problem of special interest to the student. The program will be arranged at the beginning of each semester by mutual agreement between the student and a staff member. Attendance at a weekly seminar is required. The student will write a final report and may be required to make a seminar presentation.

**700. Special Topics in Nuclear Engineering II.** *Prerequisite: permission of instructor. (To be arranged).*
Selected advanced topics such as neutron and reactor physics, reactor core design, and reactor engineering. The subject matter will change from semester to semester.

**720. Thermonuclear Theory I.** *Prerequisite: Nuc. Eng. 680.* I. *(3).*
Fundamentals of the physics of fusion and of ionized gases. The basic equations describing the collective behavior of charged particles are formulated. Some general physical implications of these equations are examined.

**721. Thermonuclear Theory II.** *Prerequisite: Nuc. Eng. 720.* II. *(3).*
Investigations in plasma dynamics based on the Boltzmann and Fokker-Planck equations. Development of the equations of magnetohydrodynamics. Study of problems of containment-pinch effect, plasma oscillation, diffusion.

**730. Nuclear Power Plant Engineering II.** *Prerequisite: Nuc. Eng. 630 or permission of instructor.* I. *(3).*
Analytical investigation of areas of special importance to the design of nuclear power plants. Includes interrelations between the nuclear performance and the fluid flow and heat transfer characteristics of the reactor system.

**731. Nuclear Power Plant Engineering III.** *Prerequisite: Nuc. Eng. 730 or permission of instructor.* II. *(3).*
Selected topics in nuclear reactor power plant engineering. Designed to prepare and assist students at the level of advanced research. Subject matter will vary according to student interest.

**750. Radiation Shielding.** *Prerequisite: Nuc. Eng. 560 and 670.* I. *(3).*
A macroscopic study of the absorption of nuclear radiation in dense materials with applications to radiation shielding. Topics considered include radiation

sources, permissible radiation levels, gamma-ray attenuation, neutron attenuation, shield optimization, heat generation and removal in shields, and other related problems.

**751. Radiation Effects in Solids.** *Prerequisite: Nuc. Eng. 670.* I and II. *(3).*
Study of the effects of high-energy radiations in solids, such as germanium and silicon. Topics such as the theory of atomic displacements, ionization effects in solids, and others relating to nuclear solid-state devices.

**752. Selected Topics in Radiation Effects.** *Prerequisite: Nuc. Eng. 751.* II. *(3).*
Luminescence and scintillation properties of solids, as applied to the detection of high energy radiations, and the examination of other solid-state phenomena and their application in nuclear technology.

**770. Theory of Nuclear Reactions I.** *Prerequisite: Nuc. Eng. 670.* I. *(3).*
Introduction to nuclear forces and the two-body problem; neutron-proton scattering and the ground state of the deuteron. Discussion of nuclear models, survey of nuclear ground states and low-lying excited states. Introduction of cross-sections to describe low energy nuclear reactions.

**771. Theory of Nuclear Reactions II.** *Prerequisite: Nuc. Eng. 770.* II. *(3).*
Study of neutron-nuclear reactions with some attention to medium effects, charged-particle nuclear reactions, photon-nuclear reactions, and beta decay. Development of neutron balance relations incorporating appropriate neutron-nuclear cross-sections.

**780. Reactor Theory II.** *Prerequisite: Nuc. Eng. 680 and Math. 552 or 557 or Phys. 452. (3).*
Perturbation theory and variational methods; asymptotic reactor theory; neutron slowing down in the infinite medium and the theory of resonance capture. Space-dependent slowing down theory. The theory of multigroup calculations. Neutron thermalization and the theory of pulsed neutron measurements. Discussion of cell calculations in heterogeneous reactors.

**781. Neutron Transport Theory.** *Prerequisite: Math. 448 or Phys. 451. (3).*
Properties and solution of the one-speed neutron transport equation. Invariance properties; escape probabilities and self-shielding; singular eigenfunction expansions; infinite medium and half-space problems, with particular emphasis on the Milne Problem. The spherical harmonics, double spherical harmonics, and $S_n$ methods, time dependent problems. Brief discussion of spectral problems and transport problems in other fields, such as radiative transfer and plasma physics.

**880. Seminar in Reactor Design.** *Prerequisite: permission of instructor. (3).*
Application of transport theory and nuclear reactor theory to specific design of reactor cores and shields. The use of digital computers and survey of existing reactor codes.

**991. Special Projects.** I, II and S.S. *(1–6).*
Individual or group investigations in a particular field or on a problem of special interest to the student. The project will be arranged at the beginning of the semester by mutual agreement between the student and a staff member.

**999. Doctoral Thesis.** I, II, and S.S. *(1–6).*

## PHYSICS*

Professor Dennison; Professors Case, Crane, Franken, Hazen, Jones, Katz, Krimm, Laporte, McCormick, Parkinson, Ross, Sanders, Sawyer, Wiedenbeck, Wolfe; Associate Professors Ford, Hecht, Lewis, Meyer, Peters, Sands, Sherman, Sinclair, Terwilliger, Weinreich; Assistant Professors Bruns, Coffin, Fischbeck, Fontana, Hendel, Lambert, Longo, Overseth, Roe, Tickle, Uberall, VanderVelde, Ward, Worthington, Wu, Zorn.

**145. Mechanics, Sound, and Heat.** *Prerequisite: preceded by Math. 115.* I and II. *(5).*
Two lectures, three recitations, and one two-hour laboratory.

**146. Electricity and Light.** *Prerequisite: Physics 145.* I and II. *(5).*
Two lectures, three recitations, and one two-hour laboratory.

**153. Elementary Mechanics.** *Prerequisite: preceded or accompanied by Math. 115 or equivalent.* I. *(4).*
Mechanics of particles, kinematics. Newton's laws of motion, wave motion in mechanical systems, special relativity. One lecture, three recitations, and one laboratory.

**154. Electricity, Light, and Modern Physics.** *Prerequisite: Physics 153 and preceded or accompanied by Math. 216 or equivalent.* II. *(4).*
Electricity and magnetism, physical optics, atomic and nuclear structure. One lecture, three recitations, and one laboratory.

**303. Introduction to the Use of Radioactive Isotopes.** *Prerequisite: Physics 126 or 146.* II. *(2).*
Sources, properties, and methods of measuring radiations; determination of safe dosage; tracer techniques and their applications.

**305. Modern Physics.** *Prerequisite: Physics 126 or 146.* I. *(2).*
A discussion of fundamental experiments on the nature of matter and electromagnetic radiation. Survey of special relativity. Bohr's quantum theory, and wave mechanics of simple systems.

**307. Modern Physics II.** *Prerequisite: Physics 126 or 146 and calculus, preferably Math. 216.* I and II. *(3).*
A survey of modern physics including an introduction to special relativity, wave mechanics, and associated particle problems. Not open to students having Physics 305.

**401. Intermediate Mechanics.** *Prerequisite: Physics 126 or 146 and Math. 216 or equivalent.* I and II. *(3).*
Study of the motion of particles and rigid bodies using Newtonian force methods. Such topics as harmonic oscillators, coupled oscillators, and planetary motion will be considered.

**402. Light.** *Prerequisite: Physics 126 or 146 and Math. 216 or equivalent.* I. *(3).*
The phenomena of physical optics, reflection, refraction, dispersion, inerference, diffraction, polarization, etc., interpreted in terms of the wave theory of light.

*College of Literature, Science, and the Arts.

**405. Intermediate Electricity and Magnetism.** *Prerequisite: Physics 126 or 146 and Math. 216 or equivalent.* I and II. *(3).*
The laws and principles of electrostatics, moving electric charges, and electromagnetism; alternating-current circuit theory, including transients.

**406. Heat and Thermodynamics.** *Prerequisite: Physics 126 or 146 and Math. 403 or equivalent.* II. *(3).*
Thermal expansion, specific heats, changes of state, and van der Waals' equation; elementary kinetic theory and the absolute scale of temperature.

**409. Classical Physics Laboratory.** *Prerequisite: admission primarily to physics, astronomy, and other science majors in the junior year by permission of instructor.* II. *(2).*
Designed to develop experimental skills as well as to acquaint the student with some of the subject matter of heat, light, and classical atomic phenomena. Completed experimental apparatus will be available for standard experiments. Technical facilities and components will be available for experiments designed by the students or for improvement of existing experiments.

**411. Mechanics of Fluids.** *Prerequisite: Physics 401.* II. *(3).*
The Navier-Stokes equation is developed and is used to treat several classical problems. The student is introduced to elementary aspects of turbulence, shock waves, and hydromagnetics.

**417. Applications of Physical Measurements to Biology.** *Prerequisite: Physics 126 and eight hours of biological science.* I. *(3).*
A review of physical instruments and techniques which are applicable to the study of biological materials.

**418. Introduction of Physics of Macromolecules.** *Prerequisite: Math. 214 and Physics 402 or permission of instructor.* II. *(3).*
Physical principles underlying the behavior and characterization of macromolecular systems, with emphasis on applications to biological processes.

**425. Introduction to Infrared Spectra.** *Prerequisite: Physics 126 or 146 and Math. 214.* I. *(2).*
The elements of infrared spectroscopy and the basic principles involved in the interpretation of Raman and infrared data in terms of molecular structure.

**427, 428. Advanced Physics for Engineers.** *Prerequisite: Math. 450, Phys. 401, 406 or equivalent.* 427, I; 428, II. *(3 each).*
Intended for honors seniors and graduate students in engineering. The first semester will be advanced classical physics (particle dynamics, Maxwell equations, hydrodynamics, and kinetic theory). The second semester will be primarily quantum physics, with emphasis on atomic, molecular, and nuclear structure.

**451, 452. Introduction to Theoretical Physics.** *Prerequisite: Physics 401 and Math. 450 or 554.* 451, I; 452, II. *(3each).*
A survey of mathematical methods employed in theoretical physics, e.g., vectors, tensors, matrices, tensor fields, boundary value problems, approximation and variational methods.

**453. Atomic and Molecular Structure.** *Prerequisite: Physics 126, Math. 403 or equivalent, and five hours of intermediate physics or physical chemistry.* I and II. *(3).*
A critical discussion of developments in atomic and molecular structure based

upon fundamental experiments and interpreted in part in terms of Schroedinger's equation.

**455. Electron Tubes.** *Prerequisite: Physics 405 and Math. 403 or equivalent.* I. *(4).*
The characteristics of electron tubes and transistors, and their functions in electric circuits such as amplifiers and oscillators. Three lectures and a laboratory.

**456. Electronic Circuits.** *Prerequisite: Physics 455.* II. *(3).*
A study of circuit elements, amplifiers, coincidence and scaling circuits, and the various types of detectors and circuits used in experimental nuclear physics. Two lectures and a laboratory.

**457. Nuclear Physics.** *Prerequisite: Physics 453.* II. *(3).*
Properties and systematics of nuclei; nuclear forces and nuclear models; understood from an experimentalist's point of view.

**459. Modern Physics Laboratory.** *Prerequisite: by permission.* I. *(2).*
Same general organization and philosophy as the Physics 409 laboratory. The subject matter will emphasize instrumentation and topics that are closely related to present-day research.

**461. Introduction to Quantum Theory.** *Prerequisite: Physics 401 and 453.* II. *(3).*
An introduction to the concepts of quantum theory. Development of Schroedinger's wave mechanics and Heisenberg's matrix mechanics with applications to simple systems.

**463. Introduction to Physics of the Solid State.** *Prerequisite: Physics 453 or permission of instructor.* II. *(3).*
Structure and physical properties of crystalline solids. Ionic crystals. Free electron theory of metals. Band theory of solids. Effects of impurities and imperfections. Theories of magnetism.

**505, 506. Electricity and Magnetism.** *Prerequisite: Physics 405 and Math. 450 or 451.* 505, I; 506, II. *(3 each).*
Electromagnetic theory; Maxwell's equations and the radiation from a Hertzian oscillator; connections with the special relativity theory.

**507. Theoretical Mechanics.** *Prerequisite: an adequate knowledge of differential equations; an introductory course in mechanics is desirable.* I. *(3).*
Lagrange equations of motion; the principle of least action. Hamilton's principle, the Hamilton-Jacobi equation; Poisson brackets.

**509. Thermodynamics.** *Prerequisite: Physics 406.* II. *(3).*
The two laws and their foundation; gas equilibra and dilute solutions; phase rule of Gibbs; theory of binary mixtures.

**510. Kinetic Theory of Matter.** *Prerequisite: Physics 509.* I. *(3).*
Kinetic and statistical methods of Boltzmann, and explanation of the second law; extension to the quantum theory; nonideal gases and the theory of the solid body; theory of radiation; fluctuation phenomena.

**511, 512, 513. Quantum Theory.** *Prerequisite: Physics 453. Physics 511 is a prerequisite for Physics 512.* 511, I; 512, 513, II. *(3 each).*
Wave mechanics, matrix mechanics, and methods of quantizations, with applications.

**618. Physics of Continuous Media.** II. *(3).*

**619. Physics of the Solid State.** I. *(3).*

**624. Cosmic Radiation.** II. *(3).*

**625. Theory of Neutron Diffusion.** I. *(3).*

**626. High-Energy Nuclear Physics.** II. *(3).*

**633. Special Problems in Fluid Dynamics.** I. *(3).*

**634. Stochastic Processes in Physics.** II. *(3).*

**638. Nuclear Theory.** II. *(3).*

**641. Magnetic Resonance.** I. *(2 or 3).*

**642. Advanced Atomic Physics.** II. *(2 or 3).*

**656. Molecular Spectra and Molecular Structure.** II. *(3).*

**715. Special Problems.** I and II. *(to be arranged).*
Qualified graduate students who desire to obtain research experience in work supervised by members of the staff may, upon consultation, elect these courses.

**806, 807. Seminar.** Topic to be announced each semester. I and II. *(2 or 3).*

**809, 810. Advanced Nuclear Physics Seminar.** I and II. *(2 or 3).*

**811, 812. Experimental Seminar.** I and II. *(2 or 3).*

**813, 814. Advanced Theoretical Physics Seminar.** I and II. *(2 or 3).*

**815, 816. High-Energy Physics Seminar.** I and II. *(2 or 3).*

## SCIENCE ENGINEERING

The following courses have been developed through interdepartmental co-operation specifically for the Science Engineering degree program. Since these courses may be taught by staff members of various departments of instruction, they are listed separately rather than placed among the offerings of any one department. They may be elected by any student who presents prerequisites equivalent to those stated in the course definitions.

**280. Engineering Design.** *Prerequisite: Math. 115.* I and II. *(3).*
A study of the general principles of engineering design applicable to all fields of engineering. Analysis and definition of the problem, synthesis and formulation of a solution, evaluation of components and the over-all system, and presentation of the finished design.

**330. Thermodynamics.** *Prerequisite: Math. 215 and 273 and Chem. 194 or 265.* I. *(4).*
Introduction to thermodynamic properties, generalized gas equations, mass, energy, and entropy balances, with examples from various fields of engineering.

**340. Rate Processes.** *Prerequisite: Sci. Eng. 330 and Math. 216.* II. *(4).*
A unified study of heat, mass, and momentum transfer and chemical kinetics, with emphasis on description, measurement, correlation, and process design.

# Committees and Faculty*

EXECUTIVE COMMITTEE

Dean S. S. ATTWOOD, *Chairman*
ex officio

S. K. CLARK, term, 1960–64
L. H. VAN VLACK, term, 1961–65
H. BENFORD, term,1962–66
A. B. MACNEE, term, 1963–67

STANDING COMMITTEE

Dean S. S. ATTWOOD, *Chairman,* H. BENFORD, R. E. BURROUGHS, S. W. CHURCHILL, S. K. CLARK, R. B. COUCH, W. G. DOW, G. V. EDMONSON, A. R. HELLWARTH, W. M. HANCOCK, H. T. JENKINS, W. KERR, G. M. MCEWEN, A. B. MACNEE, J. C. MOUZON, W. C. NELSON, J. ORMONDROYD, F. E. RICHART, L. H. VAN VLACK, and G J. VAN WYLEN.

COMMITTEE ON CLASSIFICATION

A. W. LIPPHART, *Chairman,* E. A. GLYSSON, and C. W. MCMULLEN.

COMMITTEE ON SCHOLASTIC STANDING

R. C. PORTER, *Chairman,* F. J. BEUTLER, H. S. BULL, J. J. CAREY, W. R. DEBLER, D. C. DOUGLAS, D. A. RINGE, W. S. RUMMAN, S. S. STANTON, R. E. TOWNSEND, and P. F. YOUNGDAHL.

COMMITTEE ON DISCIPLINE

A. MARIN, *Chairman,* E. F. BRATER, and A. R. HELLWARTH.

COMMITTEE ON SCHOLARSHIPS AND LOANS

R. E. CARROLL, *Chairman,* H. DIAMOND, K. W. HALL, A. R. HELLWARTH, E. J. LESHER, D. R. MASON, and J. C. MOUZON.

COMMITTEE ON CURRICULUM

L. N. HOLLAND, *Chairman,* J. G. EISLEY, E. E. HUCKE, H. J. SMITH, and F. H. WESTERVELT.

*Listed for the academic year, 1963-64.

COMMITTEE ON COMBINED COURSES WITH COLLEGE OF LITERATURE, SCIENCE, AND THE ARTS

W. C. BIGELOW, *Chairman,* R. B. HARRIS, and A. R. HELLWARTH.

COMMITEE ON FRESHMAN COUNSELING

C. W. JOHNSON, *Chairman,* H. B. BENFORD, G. V. BERG, W. C. BIGELOW, H. COLBY, A. R. HELLWARTH, R. H. HOISINGTON, R. C. JUVINALL, A. W. LIPPHART, R. F. MOSHER, J. C. MOUZON, L. J. QUACKENBUSH, D. C. RAY, M. SICHEL, and C. A. SIEBERT.

COMMITTEE ON PLACEMENT

J. G. YOUNG, *Chairman,* H. BENFORD, H. BUNING, S. K. CLARK, W. G. DOW, J. G. EISLEY, F. G. HAMMITT, R. B. HARRIS, L. J. QUACKENBUSH, G. B. WILLIAMS, and R. C. WILSON.

## AERONAUTICAL AND ASTRONAUTICAL ENGINEERING

WILBUR CLIFTON NELSON, M.S.E., *Professor of Aeronautical Engineering and Chairman of the Department of Aeronautical and Astronautical Engineering*

THOMAS CHARLES ADAMSON, JR., Ph.D., *Professor of Aeronautical Engineering*

FREDERICK JOSEPH BEUTLER, Ph.D., *Professor of Instrumentation, Department of Aeronautical and Astronautical Engineering*

HARM BUNING, M.S.E., *Professor of Aeronautical Engineering*

ELMER GRANT GILBERT, Ph.D., *Professor of Instrumentation, Department of Aeronautical and Astronautical Engineering*

DONALD THEODORE GREENWOOD, Ph.D., *Professor of Instrumentation, Department of Aeronautical and Astronautical Engineering*

ROBERT MILTON HOWE, Ph.D., *Professor of Aeronautical Engineering*

GABRIEL ISAKSON, Sc.D., *Professor of Aeronautical Engineering*

LESLIE MCLAURY JONES, B.S.E. (E.E.), *Professor of Aeronautical Engineering*

ARNOLD MARTIN KUETHE, Ph.D., *Felix Pawlowski Professor of Aerodynamics*

VI-CHENG LIU, Ph.D., *Professor of Aeronautical Engineering*

RICHARD BOYD MORRISON, Ph.D., *Professor of Aeronautical Engineering*

LAWRENCE LEE RAUCH, Ph.D., *Professor of Instrumentation, Department of Aeronautical and Astronautical Engineering*

WILLIAM LUCAS ROOT, Ph.D., *Professor of Instrumentation, Department of Aeronautical and Astronautical Engineering*

WILLIAM WALTER WILLMARTH, Ph.D., *Professor of Aeronautical Engineering*

JOE GRIFFIN EISLEY, Ph.D., *Associate Professor of Aeronautical Engineering*

EDWARD OTIS GILBERT, Ph.D., *Associate Professor of Instrumentation, Department of Aeronautical and Astronautical Engineering*

EDGAR JAMES LESHER, M.S.E. *Associate Professor of Aeronautical Engineering*

ARTHUR FREDERICK MESSITER, JR., Ph.D., *Associate Professor of Aeronautical Engineering*

JAMES ARTHUR NICHOLLS, Ph.D., *Associate Professor of Aeronautical Engineering*

RUDI SIONG-BWEE ONG, Ph.D., *Associate Professor of Aeronautical Engineering*

PAULINE MONT SHERMAN, M.S., *Associate Professor of Aeronautical Engineering*

ROBERT EUGENE CULLEN, M.S.E., *Assistant Professor of Aeronautical Engineering*

ALFRED CHRISTIAN ROBINSON, Ph.D., *Assistant Professor of Instrumentation, Department of Aeronautical and Astronautical Engineering*

MARTIN SICHEL, Ph.D., *Assistant Professor of Aeronautical Engineering*

HAROLD FREDERICK ALLEN, Ph.D., *Lecturer in Aeronautical Engineering and Research Engineer, Sponsored Research*

FREDERICK LESTER WILLIAM BARTMAN, M.S., *Lecturer in Aeronautical Engineering and Research Engineer, Sponsored Research*

LAURENCE EUGENE FOGARTY, Ph.D., *Lecturer in Aeronautical Engineering*

JAMES HAMILTON OWENS, JR., M.S.; *Lecturer in Aeronautical Engineering*

## CHEMICAL AND METALLURGICAL ENGINEERING

STUART WINSTON CHURCHILL, Ph.D., *Professor of Chemical Engineering and Chairman of the Department of Chemical and Metallurgical Engineering*

WILBUR CHARLES BIGELOW, Ph.D., *Professor of Chemical and Metallurgical Engineering*

LLOYD EARL BROWNELL, Ph.D., *Professor of Chemical and Metallurgical Engineering and of Nuclear Engineering*

RICHARD A. FLINN, Sc.D., *Professor of Metallurgical Engineering*

JAMES WRIGHT FREEMAN, Ph.D., *Professor of Metallurgical Engineering and Research Engineer, Sponsored Research*

EDWARD ERNEST HUCKE, Sc.D., *Professor of Metallurgical Engineering*

DONALD LAVERNE KATZ, Ph.D., *Professor of Chemical Engineering*

LLOYD L. KEMPE, Ph.D., *Professor of Chemical Engineering*

JOSEPH J. MARTIN, D.Sc., *Professor of Chemical and Metallurgical Engineering*

DONALD ROMAGNE MASON, Ph.D., *Professor of Chemical Engineering*

GIUSEPPE PARRAVANO, Ph.D., *Professor of Chemical and Metallurgical Engineering*

JOHN E. POWERS, Ph.D., *Professor of Chemical Engineering*

RICHARD SCHNEIDEWIND, Ph.D., *Professor of Metallurgical Engineering*

CLARENCE ARNOLD SIEBERT, Ph.D., *Professor of Chemical and Metallurgical Engineering*

MAURICE JOSEPH SINNOTT, Sc.D., *Professor of Metallurgical Engineering*

LARS THOMASSEN, Ph.D., *Professor of Chemical and Metallurgical Engineering*

LAWRENCE H. VAN VLACK, Ph.D., *Professor of Materials Engineering, Department of Chemical and Metallurgical Engineering*

GEORGE BRYMER WILLIAMS, Ph.D., *Professor of Chemical and Metallurgical Engineering*

JESSE LOUIS YORK, Ph.D., *Professor of Chemical and Metallurgical Engineering and Assistant Director, Industry Program*

EDWIN HAROLD YOUNG, M.S.E., *Professor of Chemical and Metallurgical Engineering*

JOHN CROWE BRIER, M.S., *Professor Emeritus of Chemical Engineering*

LEO LEHR CARRICK, Ph.D., *Professor Emeritus of Chemical Engineering*

RICHARD EARL BALZHISER, Ph.D., *Associate Professor of Chemical Engineering*

WILLIAM F. HOSFORD, JR., Ph.D., *Associate Professor of Metallurgical Engineering*

DONALD WILLIAM MCCREADY, Ph.D., *Associate Professor of Chemical Engineering*

ROBERT DONALD PEHLKE, Sc.D., *Associate Professor of Metallurgical Engineering*

MEHMET RASIN TEK, Ph.D., *Associate Professor of Chemical Engineering*

RICHARD EMORY TOWNSEND, Ch.E., *Associate Professor of Chemical and Metallurgical Engineering*

JOE DEAN GODDARD, Ph.D., *Assistant Professor of Chemical Engineering*

ROBERT H. KADLEC, Ph.D., *Assistant Professor of Chemical Engineering*

WALTER BERTRAM PIERCE, *Assistant Professor of Foundry Practice, Department of Chemical and Metallurgical Engineering*

WILLIAM ALLEN SPINDLER, M.S., *Assistant Professor of Metallurgical Engineering*

JAMES OSCROFT WILKES, Ph.D., *Assistant Professor of Chemical Engineering*

DALE EDWARDS BRIGGS, M.S.E., *Instructor in Chemical and Metallurgical Engineering*

BRICE CARNAHAN, M.S.E., *Instructor in Chemical Engineering and in Biostatics, Medical School*

DUDLEY ALBERT SAVILLE, M.S.E., *Instructor in Chemical Engineering*

JOHN GRENNAN, *Instructor Emeritus in Foundry Practice*

## CIVIL ENGINEERING

FRANK EDWIN RICHART, JR., Ph.D., *Professor of Civil Engineering and Chairman of the Department of Civil Engineering*
GLENN LESLIE ALT, C.E., *Professor of Civil Engineering*
GLEN VIRGIL BERG, Ph.D., *Professor of Civil Engineering*
RALPH MOORE BERRY, B.C.E., *Professor of Geodetic Engineering, Department of Civil Engineering*
JACK ADOLPH BORCHARDT, Ph.D., *Professor of Civil Engineering*
ERNEST FREDERICK BRATER, Ph.D., *Professor of Hydraulic Engineering, Department of Civil Engineering*
WILLIAM STUART HOUSEL, M.S.E., *Professor of Civil Engineering*
BRUCE GILBERT JOHNSTON, Ph.D., *Professor of Structural Engineering, Department of Civil Engineering*
JOHN CLAYTON KOHL, B.S.E. (C.E.), *Professor of Civil Engineering and Director of the Transportation Institute*
LEO MAX LEGATSKI, Sc.D., *Professor of Civil Engineering*
LAWRENCE CARNAHAN MAUGH, Ph.D., *Professor of Civil Engineering*
VICTOR LYLE STREETER, Sc.D., *Professor of Hydraulics, Department of Civil Engineering*
EARNEST BOYCE, M.S., C.E., *Professor Emeritus of Municipal and Sanitary Engineering*
ARTHUR JAMES DECKER, B.S. (C.E.), *Professor Emeritus of Civil Engineering*
WALTER JOHNSON EMMONS, A.M., *Professor Emeritus of Highway Engineering, Associate Dean Emeritus and Secretary Emeritus of the College of Engineering*
CLARENCE THOMAS JOHNSTON, C.E., *Professor Emeritus of Geodesy and Surveying*
ROBERT HENRY SHERLOCK, B.S. (C.E.), *Professor Emeritus of Civil Engineering*
DONALD NATHAN CORTRIGHT, M.S.E., *Associate Professor of Civil Engineering*
EUGENE ANDRUS GLYSSON, M.S.E., *Associate Professor of Civil Engineering*
ROBERT BLYNN HARRIS, M.S.C.E., *Associate Professor of Civil Engineering*
CLINTON LOUIS HEIMBACH, Ph.D., *Associate Professor of Civil Engineering*
FRANK EVARISTE LEGG, JR., M.S., *Associate Professor of Construction Materials, Department of Civil Engineering*
WARD KARCHER PARR, B.S.E. (Ch.E.), *Associate Professor of Highway Engineering, Department of Civil Engineering*
HAROLD JAMES MCFARLAN, B.S.E. (C.E.), *Associate Professor Emeritus of Geodetic Engineering, Department of Civil Engineering*
JOHN RUSSELL HALL, JR. Ph.D., *Assistant Professor of Civil Engineering*
WADI SALIBA RUMMAN, Ph.D., *Assistant Professor of Civil Engineering*
WALTER JACOB WEBER, JR., Ph.D., *Assistant Professor of Civil Engineering*
HAROLD JOSEPH WELCH, M.S.E., *Assistant Professor of Geodetic Engineering, Department of Civil Engineering*

George Moyer Bleekman, M.S.E., *Assistant Professor Emeritus of Geodesy and Surveying*
Robert Oscar Goetz, M.S.E. (C.E.), *Instructor in Civil Engineering*
Bruce Douglas Greenshields, Ph.D., *Lecturer in Transportation Engineering, Department of Civil Engineering, and Assistant Director of the Transportation Institute*

## ELECTRICAL ENGINEERING

William Gould Dow, M.S.E., *Professor of Electrical Engineering and Chairman of the Department of Electrical Engineering*
Stephen Stanley Attwood, M.S., *Professor of Electrical Engineering and Dean of the College of Engineering*
Richard Kemp Brown, Ph.D., *Professor of Electrical Engineering*
William Milton Brown, Dr.Eng., *Professor of Electrical Engineering and Research Engineer, Sponsored Research*
Hempstead Stratton Bull, M.S., *Professor of Electrical Engineering*
John Joseph Carey, M.S. (E.E.), *Professor of Electrical Engineering*
Chiao-Min Chu, Ph.D., *Professor of Electrical Engineering*
Louis John Cutrona, Ph.D., *Professor of Electrical Engineering*
Hansford White Farris, Ph.D., *Professor of Electrical Engineering*
Harvey Louis Garner, Ph.D., *Professor of Electrical Engineering*
Dale Mills Grimes, Ph.D., *Professor of Electrical Engineering*
Fred T. Haddock, M.S., *Professor of Electrical Engineering, Professor of Astronomy, College of Literature, Science, and the Arts, and Director, Radio Astronomy Observatory*
Gunnar Hok, E.E., *Professor of Electrical Engineering*
Lewis Nelson Holland, M.S., *Professor of Electrical Engineering*
Louis Frank Kazda, Ph.D., *Professor of Electrical Engineering*
John A. M. Lyon, Ph.D., *Professor of Electrical Engineering*
Alan Breck Macnee, Sc.D., *Professor of Electrical Engineering*
Charles Warren McMullen, Ph.D., *Professor of Electrical Engineering*
Arthur Dearth Moore, M.S., *Professor of Electrical Engineering*
Raymond Fred Mosher, S.M., *Professor of Electrical Engineering*
James Carlisle Mouzon, Ph.D., *Professor of Electrical Engineering and Associate Dean of the College of Engineering*
Gordon E. Peterson, Ph.D., *Professor of Electrical Engineering, Professor of Comunication Sciences, Department of Speech, College of Literature, Science, and the Arts, and Director of the Communication Sciences Laboratory*
Joseph Everett Rowe, Ph.D., *Professor of Electrical Engineering*
Norman Ross Scott, Ph.D., *Professor of Electrical Engineering*
Charles Bruce Sharpe, Ph.D., *Professor of Electrical Engineering, and Research Engineer, Sponsored Research*
Keeve Milton Siegel, M.S., *Professor of Electrical Engineering*

NEWBERN SMITH, Ph.D., *Professor of Electrical Engineering and Research Physicist, Sponsored Research*

MELVILLE BIGHAM STOUT, M.S., *Professor of Electrical Engineering*

GEORGE W. STROKE, Dr. es Sc., *Professor of Electrical Engineering*

WILSON P. TANNER, JR., Ph.D., *Professor of Psychology, College of Literature, Science, and the Arts and Lecturer in Electrical Engineering*

EDWIN RICHARD MARTIN, E.E., *Professor Emeritus of Electrical Engineering*

THOMAS W. BUTLER, JR., Ph.D., *Associate Professor of Electrical Engineering*

KUEI CHUANG, Ph.D., *Associate Professor of Electrical Engineering*

HOWARD DIAMOND, Ph.D., *Associate Professor of Electrical Engineering*

ARLEN R. HELLWARTH, M.S., *Associate Professor of Electrical Engineering and Assistant Dean and Secretary of the College of Engineering*

EDWARD ANTHONY MARTIN, Ph.D., *Associate Professor of Electrical Engineering and of Nuclear Engineering*

EDWARD LAWRENCE MCMAHON, Ph.D., *Associate Professor of Electrical Engineering*

MURRAY HENRI MILLER, Ph.D., *Associate Professor of Electrical Engineering*

ARCH W. NAYLOR, Ph.D., *Associate Professor of Electrical Engineering*

ANDREJS OLTE, Ph.D., *Associate Professor of Electrical Engineering*

HERSCHEL WEIL, Ph.D., *Associate Professor of Electrical Engineering*

CHAI YEH, D.Sc., *Associate Professor of Electrical Engineering*

GEORGE I. HADDAD, Ph.D., *Assistant Professor of Electrical Engineering*

ROBERT O. HARGER, Ph.D., *Assistant Professor of Electrical Engineering*

EUGENE L. LAWLER, Ph.D., *Assistant Professor of Electrical Engineering*

RONALD J. LOMAX, Ph.D., *Assistant Professor of Electrical Engineering and Associate Research Engineer, Sponsored Research*

ANDREW F. NAGY, Ph.D., *Assistant Professor of Electrical Engineering*

ANTHONY JAMES PENNINGTON, Ph.D., *Assistant Professor of Electrical Engineering*

WILLIAM A. PORTER, Ph.D., *Assistant Professor of Electrical Engineering*

DALE CARNEY RAY, Ph.D., *Assistant Professor of Electrical Engineering*

SPENCER L. BEMENT, M.S.E. (E.E.), *Instructor in Electrical Engineering*

SHU-YUN CHAN, M.S.E., *Instructor in Electrical Engineering*

HERBERT HACKER, JR., M.S.E. (E.E.), *Instructor in Electrical Engineering*

WILLIAM WOLSEY RAYMOND, M.S.E. (E.E.), *Instructor in Electrical Engineering*

TIONG S. YU, M.S.E., *Instructor in Electrical Engineering*

RICHARD F. ARNOLD, M.A., *Lecturer in Electrical Engineering*

NORMAN E. BARNETT, M.S. (Phys.), *Lecturer in Electrical Engineering and Associate Research Physicist, Institute of Science and Technology*

BEN FREDERICK BARTON, Ph.D., *Lecturer in Electrical Engineering and Research Engineer, Sponsored Research*

GEORGE R. CARIGNAN, B.S., *Lecturer in Electrical Engineering and Associate Research Engineer, Sponsored Research*

ROBERT B. CRANE, Ph.D., *Lecturer in Electrical Engineering and Research Engineer, Sponsored Research*

HAROLD C. EARLY, M.S., *Lecturer in Electrical Engineering and Research Engineer, Sponsored Research*

GILBERT O. HALL, M.S., *Lecturer in Electrical Engineering and Research Engineer, Institute of Science and Technology*

EDWIN E. HENRY, Jr., Ph.D., *Lecturer in Electrical Engineering and Research Engineer, Sponsored Research*

RALPH E. HIATT, M.S., *Lecturer in Electrical Engineering and Research Physicist, Sponsored Research*

WILLIAM N. LAWRENCE, M.S.E. (E.E.), *Lecturer in Electrical Engineering and Associate Research Engineer, Sponsored Research*

FREDERICK B. LLEWELLYN, Ph.D., *Lecturer in Electrical Engineering and Deputy for the Director and Scientific Adviser to the Director, Institute of Science and Technology*

RICHARD V. PALERMO, M.S., *Lecturer in Electrical Engineering*

HAL FREDERIC SCHULTE, JR., M.S.E., *Lecturer in Electrical Engineering and Associate Research Engineer, Sponsored Research*

ERNEST B. THERKELSEN, S.M., *Lecturer in Electrical Engineering and Research Engineer, Sponsored Research*

## ENGLISH

GEORGE MIDDLETON MCEWEN, Ph.D., *Professor of English and Chairman of the Department of English, College of Engineering*

CARL GUNARD BRANDT, LL.M., *Professor of English, College of Engineering, and Lecturer in Speech, College of Literature, Science, and the Arts*

WEBSTER EARL BRITTON, Ph.D., *Professor of English, College of Engineering*

JOSHUA MCCLENNEN, Ph.D., *Professor of English, College of Engineering*

THOMAS MITCHELL SAWYER, JR., Ph.D., *Professor of English, College of Engineering*

WILFRED MINNICH SENSEMAN, Ph.D., *Professor of English, College of Engineering*

ROBERT P. WEEKS, Ph.D., *Professor of English, College of Engineering*

CARL EDWIN BURKLUND, Ph.D., *Professor of English, College of Engineering* (on retirement furlough, 1963-64)

JESSE EARL THORNTON, A.M., *Professor Emeritus of English, College of Engineering*

IVAN HENRY WALTON, A.M., *Professor Emeritus of English, College of Engineering*

WILLIAM BYROM DICKENS, Ph.D., *Associate Professor of English, College of Engineering*

WARNE CONWELL HOLCOMBE, Ph.D., *Associate Professor of English, College of Engineering, and Assistant to Director of Summer Session*

DONALD ARTHUR RINGE, Ph.D., *Associate Professor of English, College of Engineering*

EDWARD M. SHAFTER, JR., Ph.D., *Associate Professor of English, College of Engineering*

STEPHEN SADLER STANTON, Ph.D., *Associate Professor of English, College of Engineering*

ROBERT D. BRACKETT, A.M., *Associate Professor Emeritus of English, College of Engineering*

WILLIAM HENRY EGLY, A.M., *Associate Professor Emeritus of English, College of Engineering*

CHESTER FISHER CHAPIN, Ph.D., *Assistant Professor of English, College of Engineering*

ARTHUR WILLARD FORBES, A.M., *Assistant Professor of English, College of Engineering*

LEONARD A. GREENBAUM, M.A., *Assistant Professor of English, College of Engineering, and Assistant to Director, and Editor, Phoenix Publications, Phoenix Project*

RALPH A. LOOMIS, Ph.D., *Assistant Professor of English, College of Engineering*

RICHARD JOHN ROSS, Ph.D., *Assistant Professor of English, College of Engineering*

W. HARRY MACK, A.M., *Assistant Professor Emeritus of English, College of Engineering*

ALTON LEWIS BECKER, M.A., *Instructor in English, College of Engineering*

PAUL EDWIN CORNELIUS, Ph.D., *Instructor in English, College of Engineering*

THOMAS C. EDWARDS, A.M., *Instructor in English, College of Engineering*

WILLIAM VICTOR HOLTZ, M.A., *Instructor in English, College of Engineering*

ROGER MILLIKEN JONES, M.A., *Instructor in English, College of Engineering*

PETER ROBERTS KLAVER, M.A., *Instructor in English, College of Engineering*

CHESTER RAYMOND LEACH, M.A., *Instructor in English, College of Engineering*

JOHN CHARLES MATHES, M.A., *Instructor in English, College of Engineering*

MYRON BERKLEY SHAW, Ph.D., *Instructor in English, College of Engineering*

DAVID BRUCE SPAAN, M.A., *Instructor in English, College of Engineering*

DWIGHT WARD STEVENSON, M.A., *Instructor in English, College of Engineering*

RICHARD EMERSON YOUNG, M.A., *Instructor in English, College of Engineering*

## ENGINEERING GRAPHICS

Herbert Theodore Jenkins, M.S.E., *Professor of Engineering Graphics and Chairman of the Department of Engineering Graphics*
Philip Orland Potts, M.S.E., *Professor of Engineering Graphics* (on retirement furlough, 1964)
Frank Harold Smith, M.S.E., *Professor of Engineering Graphics*
Robert Carl Cole, A.M., *Professor Emeritus of Engineering Drawing*
Dean Estes Hobart, B.S., *Professor Emeritus of Engineering Drawing*
Henry Willard Miller, M.E., *Professor Emeritus of Engineering Drawing*
Martin J. Orbeck, C.E., M.S.E., *Professor Emeritus of Engineering Drawing*
Julius Clark Palmer, B.S., *Professor Emeritus of Engineering Graphics*
Donald Craig Douglas, B.S.M.E., *Associate Professor of Engineering Graphics*
Robert Seaton Heppinstall, M.S. (M.E.), *Associate Professor of Engineering Graphics*
Robert Horace Hoisington, M.S., *Associate Professor of Engineering Graphics and Assistant to the Dean of the College of Engineering*
Alfred William Lipphart, B.S.E. (Ae.E.), LL.B., *Associate Professor of Engineering Graphics*
Kurt Christian Binder, B.S.E. (M.E.), M.B.A., *Assistant Professor of Engineering Graphics*
Francis X. Lake, Ph.D., *Assistant Professor of Engineering Graphics (on retirement furlough, 1964)*
Raymond Clare Scott, M.S. (Ed.), *Assistant Professor of Engineering Graphics*
Albert Loring Clark, Jr., B.S.E. (M.E.), *Assistant Professor Emeritus of Engineering Drawing*
Thomas M. Atkins, B.S.E. (M.E.), *Instructor in Engineering Graphics*
Douglas Folger Thompson, B.S. (I.E.), *Instructor in Engineering Graphics*
Philip Edward Webb, M.S.E., *Instructor in Engineering Graphics*

## ENGINEERING MECHANICS

Jesse Ormondroyd, A.B., *Professor of Engineering Mechanics and Chairman of the Department of Engineering Mechanics*
Samuel Kelly Clark, Ph.D., *Professor of Engineering Mechanics*
Russell Alger Dodge, M.S.E., *Professor of Engineering Mechanics and Chairman of the Department of Engineering Mechanics* (on retirement furlough, 1963-64)
John Hermann Enns, Ph.D., *Professor of Engineering Mechanics*

ROBERT MORPHET HAYTHORNTHWAITE, Ph.D., *Professor of Engineering Science, Department of Engineering Mechanics*
ROBERT LAWRENCE HESS, Ph.D., *Professor of Engineering Mechanics and Associate Director, Institute of Science and Technology* (absent on leave from Engineering Mechanics)
ERNEST FRANK MASUR, Ph.D., *Professor of Engineering Mechanics*
HADLEY JAMES SMITH, Ph.D., *Professor of Engineering Mechanics*
CHIA-SHUN YIH, Ph.D., *Professor of Engineering Mechanics*
EDWARD LEERDRUP ERIKSEN, B.C.E., *Professor Emeritus of Engineering Mechanics*
HOLGER MADS HANSEN, B.C.E., *Professor Emeritus of Engineering Mechanics*
RICHARD THOMAS LIDDICOAT, Ph.D., *Professor Emeritus of Engineering Mechanics*
FERDINAND NORTHRUP MENEFEE, C.E., D.Eng., *Professor Emeritus of Engineering Mechanics*
CHARLES THOMAS OLMSTED, B.S. (C.E.), *Professor Emeritus of Engineering Mechanics*
WALTER RALPH DEBLER, Ph.D., *Associate Professor of Engineering Mechanics*
FRANKLIN LELAND EVERETT, Ph.D., *Associate Professor of Engineering Mechanics*
WILLIAM PAUL GRAEBEL, Ph.D., *Associate Professor of Engineering Mechanics*
BERTRAM HERZOG, Ph.D., *Associate Professor of Engineering Mechanics*
DAVID RICHARD JENKINS, Ph.D., *Assistant Professor of Engineering Mechanics*
MOVSES JEREMY KALDJIAN, Ph.D., *Assistant Professor of Engineering Mechanics*
IVOR KEEN McIVOR, Ph.D., *Assistant Professor of Engineering Mechanics*
ROBERT LORAIN ARMSTRONG, M.S.E., *Instructor in Engineering Mechanics*
PHILIP KIETH DAVIS, M.S.E., *Instructor in Engineering Mechanics*
PHILIP GERALD KESSEL, M.S. (M.E.), *Instructor in Engineering Mechanics*
DEAN TRITCHLER MOOK, M.S., *Instructor in Engineering Mechanics*
MERLE CLARENCE POTTER, *Instructor in Engineering Mechanics*
YOUNG KING LIU, Ph.D., *Lecturer in Engineering Mechanics*
RAYMOND JOSEPH STITH, M.S.C.E., *Lecturer in Engineering Mechanics*

## INDUSTRIAL ENGINEERING

WALTON MILTON HANCOCK, D.Eng., *Professor of Industrial Engineering and Chairman of the Department of Industrial Engineering*
MERRILL MEEKS FLOOD, Ph.D., *Professor of Industrial Engineering, Professor and Senior Research Mathematician, Mental Health Research Institute, and Professor of Mathematical Biology, Department of Psychiatry, Medical School*

JAMES ARNOLD GAGE, M.S. (M.E.), *Professor of Industrial Engineering*
HERBERT P. GALLIHER, Ph.D., *Professor of Industrial Engineering*
ROBERT MCDOWELL THRALL, Ph.D., Sc.D., *Professor of Operations Analysis, Department of Industrial Engineering, and Professor of Mathematics, College of Literature, Science, and the Arts*
WYETH ALLEN, B.M.E., D.Eng., *Professor Emeritus of Industrial Engineering*
FREDERICK LEE BLACK, A.B., *Professor Emeritus of Industrial Engineering and Director Emeritus of Business Relations, School of Business Administration*
RALPH L. DISNEY, M.S.E., *Visiting Associate Professor of Industrial Engineering*
CLYDE WIMOUTH JOHNSON, A.B., *Associate Professor of Industrial Engineering*
EDWARD LUPTON PAGE, M.S.E. (I.E.), *Associate Professor of Industrial Engineering*
WILBERT STEFFY, B.S.E. (Ind.-Mech.), B.S.E. (M.E.), *Associate Professor of Industrial Engineering*
QUENTIN C. VINES, M.E., *Associate Professor of Industrial Engineering*
RICHARD CHRISTIAN WILSON, Ph.D., *Associate Professor of Industrial Engineering*
RICHARD WATSON BERKELEY, B.S.A. (M.&I.E.), *Assistant Professor of Industrial Engineering*
HUGH E. BRADLEY, Ph.D., *Assistant Professor of Industrial Engineering*
JAMES A. FOULKE, B.S.E. (E.E.), *Lecturer in Industrial Engineering and Assistant Research Engineer in Industrial Engineering*
RICHARD R. LEGAULT, M.A., *Lecturer in Industrial Engineering and Research Mathematician, Institute of Science and Technology*
DEAN HURLBUT WILSON, B.S. (E.E.), *Lecturer in Industrial Engineering and Research Engineer, Sponsored Research*

## MECHANICAL ENGINEERING

GORDON JOHN VAN WYLEN, Sc.D., *Professor of Mechanical Engineering and Chairman of the Department of Mechanical Engineering*
HERBERT HERLE ALVORD, M.S.E., *Professor of Mechanical Engineering*
JAY ARTHUR BOLT, M.S., M.E., *Professor of Mechanical Engineering*
JOHN ALDEN CLARK, Sc.D., *Professor of Mechanical Engineering*
LESTER VERN COLWELL, M.S., *Professor of Mechanical Engineering*
JOSEPH DATSKO, M.S.E., *Professor of Mechanical Engineering*
GLENN VERNON EDMONSON, M.E., *Professor of Mechanical Engineering and Associate Dean of the College of Engineering*
RUNE L. EVALDSON, Ph.D., *Professor of Mechanical Engineering and Associate Director, Institute of Science and Technology* (absent on leave from Mechanical Engineering)

WILLIAM HORACE GRAVES, B.S.E. (Ch.E.), *Professor of Automotive Engineering, Department of Mechanical Engineering*

KEITH WILLIS HALL, B.S.M.E., *Professor of Mechanical Engineering*

ARTHUR GENE HANSEN, Ph.D., *Professor of Mechanical Engineering*

ROBERT CHARLES JUVINALL, M.S.M.E., *Professor of Mechanical Engineering*

CHARLES LIPSON, Ph.D., *Professor of Mechanical Engineering*

AXEL MARIN, B.S.E. (M.E.), *Professor of Mechanical Engineering*

JOHN RAYMOND PEARSON, M.Sc.M.E., *Professor of Mechanical Engineering*

RICHMOND CLAY PORTER, M.S., M.E., *Professor of Mechanical Engineering*

JOSEPH EDWARD SHIGLEY, M.S.E., *Professor of Mechanical Engineering*

ORLAN WILLIAM BOSTON, M.S.E., M.E., *Professor Emeritus of Mechanical Engineering and of Production Engineering*

FLOYD NEWTON CALHOON, M.S., *Professor Emeritus of Mechanical Engineering*

RANSOM SMITH HAWLEY, M.E., *Professor Emeritus of Mechanical Engineering*

HUGH EDWARD KELLER, M.S.E., M.E., *Professor Emeritus of Mechanical Engineering*

WALTER EDWIN LAY, B.M.E., *Professor Emeritus of Mechanical Engineering*

EDWARD THOMAS VINCENT, B.Sc., *Professor Emeritus of Mechanical Engineering*

JOSEPH REID AKERMAN, Ph.D., *Associate Professor of Mechanical Engineering*

VEDAT S. ARPACI, Sc.D., *Associate Professor of Mechanical Engineering*

HOWARD REX COLBY, M.S.E., *Associate Professor of Mechanical Engineering*

ARNET BERTHOLD EPPLE, M.S., *Associate Professor of Mechanical Engineering*

DAVID KNISELEY FELBECK, Sc.D., *Associate Professor of Mechanical Engineering*

EDWARD RUSSEL LADY, Ph.D., *Associate Professor of Mechanical Engineering*

HERMAN MERTE, JR., Ph.D., *Associate Professor of Mechanical Engineering*

WILLIAM MIRSKY, Ph.D., *Associate Professor of Mechanical Engineering*

LELAND JAMES QUACKENBUSH, M.S.E. (M.E.), *Associate Professor of Mechanical Engineering*

RICHARD EDWIN SONNTAG, Ph.D., *Associate Professor of Mechanical Engineering*

FRANKLIN HERBERT WESTERVELT, Ph.D., *Associate Professor of Mechanical Engineering*

PAUL F. YOUNGDAHL, Ph.D., *Associate Professor of Mechanical Engineering*

ROBERT MACORMAC CADDELL, Ph.D., *Assistant Professor of Mechanical Engineering*

JULIAN ROSS FREDERICK, Ph.D., *Assistant Professor of Mechanical Engineering*

ALEXANDER HENKEN, Ph.D., *Assistant Professor of Mechanical Engineering*

ROBERT BRINDLE KELLER, Ph.D., *Assistant Professor of Mechanical Engineering*

KENNETH C. LUDEMA, Ph.D., *Assistant Professor of Mechanical Engineering*
JOSEPH CASMERE MAZUR, M.S.E., *Assistant Professor of Mechanical Engineering*
GENE EVERETT SMITH, Ph.D., *Assistant Professor of Mechanical Engineering*
FREDERICK JOHN VESPER, M.S.E., *Assistant Professor of Mechanical Engineering*
LESLIE E. WAGNER, M.A., *Assistant Professor of Mechanical Engineering*
WARD OTIS WINER, Ph.D., *Assistant Professor of Mechanical Engineering*
WEN-JEI YANG, Ph.D., *Assistant Professor of Mechanical Engineering*
JOHN GRAHAM YOUNG, B.S.E. (M.E.), *Assistant Professor of Mechanical Engineering and Assistant to the Dean of the College of Engineering*
HARRY JAMES WATSON, B.M.E., *Assistant Professor Emeritus of Mechanical Engineering*
WILLIAM TELFER, *Instructor Emeritus in the Working, Treating, and Welding of Steel*
FRANCIS ELWYN FISHER, B.S., *Lecturer in Mechanical Engineering*

## METEOROLOGY AND OCEANOGRAPHY

AKSEL C. WIIN-NIELSEN, Fil. Dr., *Professor of Meteorology and Oceanography and Chairman of the Department of Meteorology and Oceanography*
JOHN C. AYERS, Ph.D., *Professor of Oceanography*
ALBERT NELSON DINGLE, Sc.D., *Professor of Meteorology*
EDGAR WENDELL HEWSON, Ph.D., *Professor of Meteorology*
JACK L. HOUGH, Ph.D., *Professor of Oceanography*
DONALD J. PORTMAN, Ph.D., *Professor of Meteorology*
EDWARD S. EPSTEIN, Ph.D., *Associate Professor of Meteorology*
GERALD CLIFFORD GILL, M.A., *Associate Professor of Meteorology*
ALAN L. COLE, Ph.D., *Lecturer in Meteorology*
JOHN A. LEESE, M.S., *Lecturer in Meteorology*

## NAVAL ARCHITECTURE AND MARINE ENGINEERING

RICHARD BAILEY COUCH, Ae.E., *Professor of Naval Architecture and Marine Engineering and Chairman of the Department of Naval Architecture and Marine Engineering*
HARRY BENFORD, B.S.E. (Nav.Arch.&Mar.E.), *Professor of Naval Architecture and Marine Engineering*
AMELIO M. D'ARCANGELO, M.S., *Professor of Naval Architecture and Marine Engineering*
GEORGE LAUMAN WEST, JR., B.S.E. (Nav.Arch.&Mar.E.), *Professor of Naval Architecture and Marine Engineering and of Nuclear Engineering*

HENRY CARTER ADAMS 2d, M.S., *Professor Emeritus of Naval Architecture and Marine Engineering*
LOUIS A. BAIER, B.Mar.E., Nav.Arch., *Professor Emeritus of Naval Architecture and Marine Engineering*
FINN CHRISTIAN MICHELSEN, Ph.D., *Associate Professor of Naval Architecture and Marine Engineering*
RAYMOND A. YAGLE, M.S.E., *Associate Professor of Naval Architecture and Marine Engineering*

## NUCLEAR ENGINEERING

WILLIAM KERR, Ph.D., *Professor of Nuclear Engineering and Chairman of the Department of Nuclear Engineering*
LLOYD EARL BROWNELL, Ph.D., *Professor of Nuclear Engineering and of Chemical and Metallurgical Engineering*
HENRY JACOB GOMBERG, Ph.D., *Professor of Nuclear Engineering*
FREDERICK GNICHTEL HAMMITT, Ph.D., *Professor of Nuclear Engineering*
CHIHIRO KIKUCHI, Ph.D., *Professor of Nuclear Engineering*
JOHN SWINTON KING, Ph.D., *Professor of Nuclear Engineering*
RICHARD KENT OSBORN, Ph.D., *Professor of Nuclear Engineering*
GEORGE LAUMAN WEST, JR., B.S.E. (Nav.Arch.&Mar.E.), *Professor of Nuclear Engineering and of Naval Architecture and Marine Engineering*
PAUL FREDERICK ZWEIFEL, Ph.D., *Professor of Nuclear Engineering*
TERRY B. KAMMASH, Ph.D., *Associate Professor of Nuclear Engineering*
EDWARD ANTHONY MARTIN, Ph.D., *Associate Professor of Nuclear Engineering and of Electrical Engineering*
DIETRICH HERMANN VINCENT, Dr. Rer. Nat., *Associate Professor of Nuclear Engineering*
ZIYA A. AKCASU, Ph.D., *Assistant Professor of Nuclear Engineering*
GEZA LESLIE GYOREY, Ph.D., *Assistant Professor of Nuclear Engineering*
GLENN FREDERICK KNOLL, Ph.D., *Assistant Professor of Nuclear Engineering*
FRED CHARLES SHURE, Ph.D., *Assistant Professor of Nuclear Engineering*
GEORGE C. SUMMERFIELD, Ph.D., *Assistant Professor of Nuclear Engineering*

## Registration Schedules, 1964—1965

Each of the following groups of students is allotted a definite period for admission to the gymnasiums for registration. Please complete all registration forms distinctly and according to directions on the forms *before you enter the gymnasium.* Elections should be approved previously as specified in the *Announcement* of your school or college.

### FALL SEMESTER, 1964

**WEDNESDAY AUGUST 26, 1964**

| A.M. | | | P.M. | | |
|---|---|---|---|---|---|
| 8:00— 8:10 | Patt | —Pea | 1:00—1:10 | Sa | —Sarg |
| 8:10— 8:20 | Peb | —Pere | 1:10—1:20 | Sarh | —Schl |
| 8:20— 8:30 | Perf | —Pete | 1:20—1:30 | Schm | —Schwartz, R. |
| 8:30— 8:40 | Petf | —Pick | 1:30—1:40 | Schwartz, S. | —Send |
| 8:40— 8:50 | Picl | —Pli | 1:40—1:50 | Sene | —Shel |
| 8:50— 9:00 | Plj | —Pop | 1:50—2:00 | Shem | —Siel |
| 9:00— 9:10 | Poq | —Pow | 2:00—2:10 | Siem | —Sk |
| 9:10— 9:20 | Pox | —Pri | 2:10—2:20 | Sl | —Smith, L. |
| 9:20— 9:30 | Prj | —Qur | 2:20—2:30 | Smith, M. | —Sol |
| 9:30— 9:40 | Qus | —Ram | 2:30—2:40 | Som | —Stah |
| 9:40— 9:50 | Ran | —Raz | 2:40—2:50 | Stai | —Steu |
| 9:50—10:00 | Rb | —Reid, S. | 2:50—3:00 | Stev | —Sto |
| 10:00—10:10 | Reid, T. | —Rex | 3:00—3:10 | Stp | —Sup |
| 10:10—10:20 | Rey | —Richa | 3:10—3:20 | Suq | —Tas |
| 10:20—10:30 | Richb | —Ris | 3:20—3:30 | Tat | —Thomp |
| 10:30—10:40 | Rit | —Robertsn | 3:30—3:40 | Thomq | —Toml |
| 10:40—10:50 | Robertso | —Rod | 3:40—3:50 | Tomm | —Tup |
| 10:50—11:00 | Roe | —Rop | 3:50—4:00 | Tuq | —Vandeq |
| 11:00—11:10 | Roq | —Rosm | 4:00—4:10 | Vander | —Ver |
| 11:10—11:20 | Rosn | —Rot | 4:10—4:20 | Ves | —Walc |
| 11:20—11:30 | Rou | —Rz | 4:20—4:30 | Wald | —Wark |

**THURSDAY AUGUST 27, 1964**

| A.M. | | | P.M. | | |
|---|---|---|---|---|---|
| 8:00— 8:10 | Warl | —Webe | 1:00—1:10 | Brb | —Brown, F. |
| 8:10— 8:20 | Webf | —Wer | 1:10—1:20 | Brown, G. | —Buc |
| 8:20— 8:30 | Wes | —Wh | 1:20—1:30 | Bud | —Bur |
| 8:30— 8:40 | Wi | —Willi | 1:30—1:40 | Bus | —Cam |
| 8:40— 8:50 | Willj | —Wolc | 1:40—1:50 | Can | —Car |
| 8:50— 9:00 | Wold | —Wre | 1:50—2:00 | Cas | —Cha |
| 9:00— 9:10 | Wrf | —Yz | 2:00—2:10 | Chb | —Ci |
| 9:10— 9:20 | Za | —Zz | 2:10—2:20 | Cj | —Cohe |
| 9:20— 9:30 | Aa | —Alc | 2:20—2:30 | Cohf | —Con |
| 9:30— 9:40 | Ald | —Anderse | 2:30—2:40 | Coo | —Cou |
| 9:40— 9:50 | Andersf | —Ark | 2:40—2:50 | Cov | —Cro |
| 9:50—10:00 | Arl | —Bab | 2:50—3:00 | Crp | —Dam |
| 10:00—10:10 | Bac | —Baq | 3:00—3:10 | Dan | —Daz |
| 10:10—10:20 | Bar | —Bas | 3:10—3:20 | Db | —Deng |
| 10:20—10:30 | Bat | —Bec | 3:20—3:30 | Denh | —Din |
| 10:30—10:40 | Bed | —Benr | 3:30—3:40 | Dio | —Dou |
| 10:40—10:50 | Bens | —Bes | 3:40—3:50 | Dov | —Dup |
| 10:50—11:00 | Bet | —Blac | 3:50—4:00 | Duq | —Eg |
| 11:00—11:10 | Blad | —Boe | 4:00—4:10 | Eh | —En |
| 11:10—11:20 | Bof | —Bot | 4:10—4:20 | Eo | —Fan |
| 11:20—11:30 | Bou | —Bra | 4:20—4:30 | Fao | —Fil |

**FRIDAY AUGUST 28, 1964**

| A.M. | | | P.M. | | |
|---|---|---|---|---|---|
| 8:00— 8:10 | Fim | —Foc | 1:00—1:10 | Kan | —Kea |
| 8:10— 8:20 | Fod | —Fran | 1:10—1:20 | Keb | —Ker |
| 8:20— 8:30 | Frao | —Fz | 1:20—1:30 | Kes | —Kiq |
| 8:30— 8:40 | Ga | —Gau | 1:30—1:40 | Kir | —Kni |
| 8:40— 8:50 | Gav | —Gill | 1:40—1:50 | Knj | —Koth |
| 8:50— 9:00 | Gilm | —Goldl | 1:50—2:00 | Koti | —Krug |
| 9:00— 9:10 | Goldm | —Grah | 2:00—2:10 | Kruh | —Lami |
| 9:10— 9:20 | Grai | —Gri | 2:10—2:20 | Lamj | —Lawre |
| 9:20— 9:30 | Grj | —Had | 2:20—2:30 | Lawrf | —Lewi |
| 9:30— 9:40 | Hae | —Ham | 2:30—2:40 | Lewj | —Luca |
| 9:40— 9:50 | Han | —Harrisn | 2:40—2:50 | Lucb | —M(a)cGi |
| 9:50—10:00 | Harriso | —Hd | 2:50—3:00 | M(a)cGj | —Mall |
| 10:00—10:10 | Hea | —Henl | 3:00—3:10 | Malm | —Mat |
| 10:10—10:20 | Henm | —Hile | 3:10—3:20 | Mau | —Miller, E. |
| 10:20—10:30 | Hilf | —Holl | 3:20—3:30 | Miller, F. | —Moro |
| 10:30—10:40 | Holm | —How | 3:30—3:40 | Morp | —Nax |
| 10:40—10:50 | Hox | —Hur | 3:40—4:00 | Nay | —Nz |
| 10:50—11:00 | Hus | —Jack | 4:00—4:10 | Oa | —Pak |
| 11:00—11:10 | Jacl | —Jog | 4:10—4:20 | Pal | —Pats |
| 11:10—11:20 | Joh | —Jones, J. | | | |
| 11:20—11:30 | Jones, K. | —Kam | | | |

## SPRING SEMESTER, 1965

**WEDNESDAY**
**JANUARY 13, 1965**

| A.M. | | | P.M. | | |
|---|---|---|---|---|---|
| 8:00— 8:10 | Sa | —Sals | 1:00—1:10 | Stev | —Sto |
| 8:10— 8:20 | Salt | —Sarg | 1:10—1:20 | Stp | —Sup |
| 8:20— 8:30 | Sarh | —Schaf | 1:20—1:30 | Suq | —Tas |
| 8:30— 8:40 | Schag | —Schl | 1:30—1:40 | Tat | —Thomp |
| 8:40— 8:50 | Schm | —Schs | 1:40—1:50 | Thomq | —Toml |
| 8:50— 9:00 | Scht | —Schwartz, R. | 1:50—2:00 | Tomm | —Tup |
| 9:00— 9:10 | Schwartz, S. | —Seba | 2:00—2:10 | Tuq | —Vandeq |
| 9:10— 9:20 | Sebb | —Send | 2:10—2:20 | Vander | —Ver |
| 9:20— 9:30 | Sene | —Shap | 2:20—2:30 | Ves | —Walc |
| 9:30— 9:40 | Shaq | —Shel | 2:30—2:40 | Wald | —Wark |
| 9:40— 9:50 | Shem | —Shi | 2:40—2:50 | Warl | —Webe |
| 9:50—10:00 | Shj | —Siel | 2:50—3:00 | Webf | —Wer |
| 10:00—10:10 | Siem | —Sim | 3:00—3:10 | Wes | —Wh |
| 10:10—10:20 | Sin | —Sk | 3:10—3:20 | Wi | —Willi |
| 10:20—10:30 | Sl | —Smith, C. | 3:20—3:30 | Willj | —Wolc |
| 10:30—10:40 | Smith, D. | —Smith, L. | 3:30—3:40 | Wold | —Wre |
| 10:40—10:50 | Smith, M. | —Smz | 3:40—3:50 | Wrf | —Yz |
| 10:50—11:00 | Sn | —Sol | 3:50—4:00 | Za | —Zz |
| 11:00—11:10 | Som | —Spen | 4:00—4:10 | Aa | —Alc |
| 11:10—11:20 | Speo | —Stah | 4:10—4:20 | Ald | —Anderse |
| 11:20—11:30 | Stai | —Steu | 4:20—4:30 | Andersf | —Ark |

**THURSDAY**
**JANUARY 14, 1965**

| A.M. | | | P.M. | | |
|---|---|---|---|---|---|
| 8:00— 8:10 | Arl | —Bab | 1:00—1:10 | Crp | —Dam |
| 8:10— 8:20 | Bac | —Baq | 1:10—1:20 | Dan | —Daz |
| 8:20— 8:30 | Bar | —Bas | 1:20—1:30 | Db | —Deng |
| 8:30— 8:40 | Bat | —Bec | 1:30—1:40 | Denh | —Din |
| 8:40— 8:50 | Bed | —Benr | 1:40—1:50 | Dio | —Dou |
| 8:50— 9:00 | Bens | —Bes | 1:50—2:00 | Dov | —Dup |
| 9:00— 9:10 | Bet | —Blac | 2:00—2:10 | Duq | —Eg |
| 9:10— 9:20 | Blad | —Boe | 2:10—2:20 | Eh | —En |
| 9:20— 9:30 | Bof | —Bot | 2:20—2:30 | Eo | —Fan |
| 9:30— 9:40 | Bou | —Bra | 2:30—2:40 | Fao | —Fil |
| 9:40— 9:50 | Brb | —Brown, F. | 2:40—2:50 | Fim | —Foc |
| 9:50—10:00 | Brown, G. | —Buc | 2:50—3:00 | Fod | —Fran |
| 10:00—10:10 | Bud | —Bur | 3:00—3:10 | Frao | —Fz |
| 10:10—10:20 | Bus | —Cam | 3:10—3:20 | Ga | —Gau |
| 10:20—10:30 | Can | —Car | 3:20—3:30 | Gav | —Gill |
| 10:30—10:40 | Cas | —Cha | 3:30—3:40 | Gilm | —Goldl |
| 10:40—10:50 | Chb | —Ci | 3:40—3:50 | Goldm | —Grah |
| 10:50—11:00 | Cj | —Cohe | 3:50—4:00 | Grai | —Gri |
| 11:00—11:10 | Cohf | —Con | 4:00—4:10 | Grj | —Had |
| 11:10—11:20 | Coo | —Cou | 4:10—4:20 | Hae | —Ham |
| 11:20—11:30 | Cov | —Cro | 4:20—4:30 | Han | —Harrisn |

**FRIDAY**
**JANUARY 15, 1965**

| A.M. | | | P.M. | | |
|---|---|---|---|---|---|
| 8:00— 8:10 | Harriso | —Hd | 1:00—1:10 | Liu | —Luca |
| 8:10— 8:20 | Hea | —Henl | 1:10—1:20 | Lucb | —M(a)cClel |
| 8:20— 8:30 | Henm | —Hile | 1:20—1:30 | M(a)cClem | —M(a)cGi |
| 8:30— 8:40 | Hilf | —Holl | 1:30—1:40 | M(a)cGj | —M(a)cMa |
| 8:40— 8:50 | Holm | —How | 1:40—1:50 | M(a)cMb | —Mall |
| 8:50— 9:00 | Hox | —Hur | 1:50—2:00 | Malm | —Mat |
| 9:00— 9:10 | Hus | —Jack | 2:00—2:10 | Mau | —Miller, E. |
| 9:10— 9:20 | Jacl | —Jog | 2:10—2:20 | Miller, F. | —Moro |
| 9:20— 9:30 | Joh | —Jones, J. | 2:20—2:30 | Morp | —Nax |
| 9:30— 9:40 | Jones, K. | —Kam | 2:30—2:40 | Nay | —Nz |
| 9:40— 9:50 | Kan | —Kea | 2:40—2:50 | Oa | —Pak |
| 9:50—10:00 | Keb | —Ker | 2:50—3:00 | Pal | —Pere |
| 10:00—10:10 | Kes | —Kiq | 3:00—3:10 | Perf | —Pop |
| 10:10—10:20 | Kir | —Kni | 3:10—3:20 | Poq | —Ram |
| 10:20—10:30 | Knj | —Koth | 3:20—3:30 | Ran | —Richa |
| 10:30—10:40 | Koti | —Krug | 3:30—3:40 | Richb | —Rop |
| 10:40—10:50 | Kruh | —Lami | 3:40—4:00 | Roq | —Rz |
| 10:50—11:00 | Lamj | —Lawre | | | |
| 11:00—11:10 | Lawrf | —Leis | | | |
| 11:10—11:20 | Leit | —Lewi | | | |
| 11:20—11:30 | Lewj | —Lit | | | |

# Index

# University of Michigan Official Publication

University of Michigan Official Publication is the title given to the series of administrative bulletins published by the University. This series includes the following:

## BULLETINS FOR PROSPECTIVE STUDENTS

The prospective student should have, in addition to a copy of the bulletin *General Information,* a copy of one or more of the announcements or bulletins listed under this head. These will be sent, without charge, on request to The University of Michigan.

General Information

Announcements:

- Architecture and Design, College of
- Business Administration, Graduate School of
- Business Administration, School of
- Dearborn Campus
- Dentistry, School of
- Education, School of
- Engineering, College of
- Flint College
- Graduate Dentistry, W. K. Kellogg Foundation Institute
- Graduate Studies, Horace H. Rackham School of
- Law School
- Literature, Science, and the Arts, College of
- Medical School
- Music, School of
- Natural Resources, School of
- Nursing, School of
- Pharmacy, College of
- Postgraduate Dentistry, W. K. Kellogg Foundation Institute
- Public Administration, Institute of
- Public Health, School of
- Social Work, School of
- Summer Session

## OTHER BULLETINS

Extension courses

Bulletins describing the work of various departments and curriculums

For general information concerning the University, address The University of Michigan, Ann Arbor, Michigan.