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College of Engineering 1968-69
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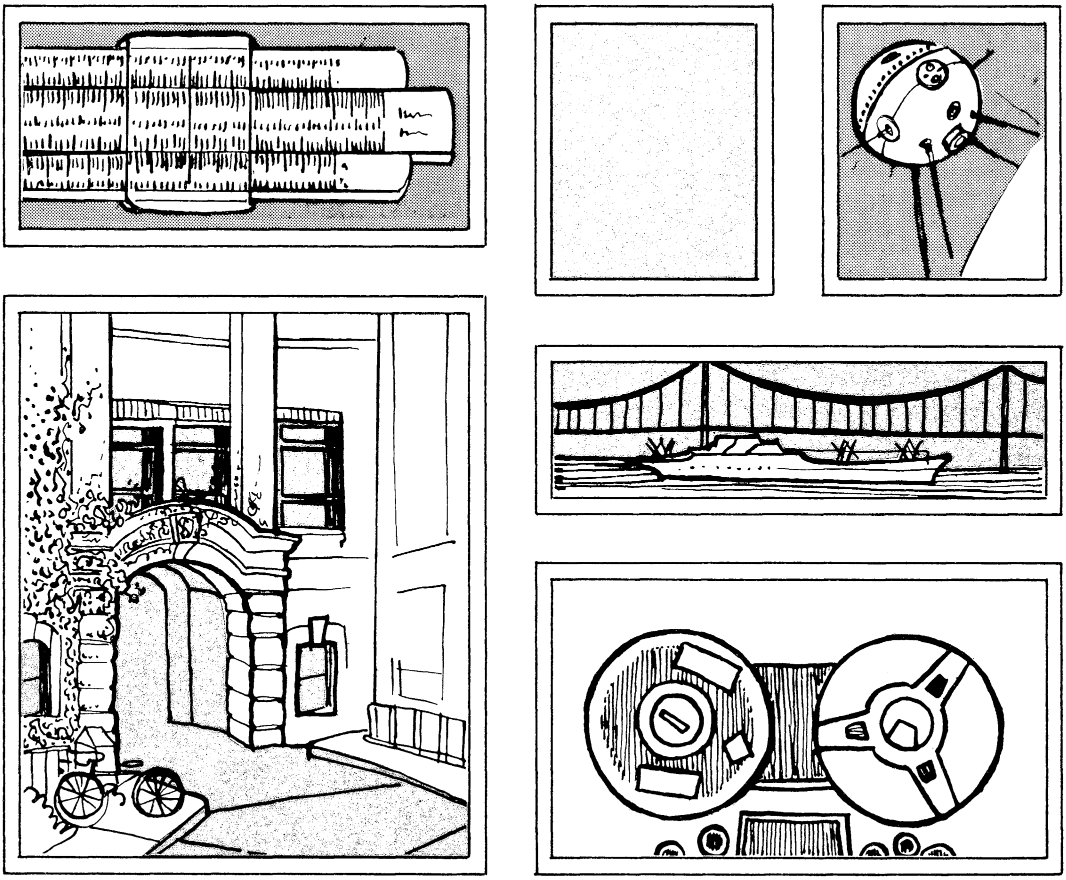

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College of Engineering

Announcement

1968-1969

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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 term 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 Half Term Office, 3510 Administration

Veterans Affairs, 1513 Administration Building

College of Engineering Offices

For information: Area Code 313, Telephone 764-8470

Admissions: Advanced Standing, 259 West Engineering

Deans of the College:
- Dean Gordon J. Van Wylen, 255 West Engineering
- Associate Dean J. G. Eisley, 1520F East Engineering
- Associate Dean H. W. Farris, 268 West Engineering
- Associate Dean and Secretary A. R. Hellwarth, 259 West Engineering
- Associate Dean N. R. Scott, 248 West Engineering
- Assistant Dean R. H. Hoisington, 259 West Engineering
- Assistant to the Dean R. E. Carroll, 273 Chrysler Center
- Assistant to the Dean A. W. Lipphart, 441 West Engineering
- Assistant to the Dean I .K. McAdam, 312 Automotive Engineering Laboratory
- Assistant to the Dean J. G. Young, 128H West Engineering

Freshman Counseling, 265 West Engineering

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Calendar, 1968-69

Fall Term, 1968

Orientation begins	August 21, Wednesday
Registration begins	August 26, Monday
Classes begin	August 29, Thursday
Labor Day, a holiday	September 2, Monday
Thanksgiving recess begins	5 p.m., November 27, Wednesday
Classes resume	8 a.m., December 2, Monday
Classes end	December 6, Friday
Study days	December 7, 9–10, Saturday, Monday–Tuesday
Examination period	December 11–17, Wednesday–Tuesday
Winter Commencement	December 14, Saturday

Winter Term, 1969

Registration begins	January 6, Monday
Classes begin	January 9, Thursday
Winter term recess begins	5 p.m., March 5, Wednesday
Classes resume	8 a.m., March 10, Monday
Classes end	April 18, Friday
Study days	April 19, 21–22, Saturday, Monday–Tuesday
Examination period	April 23–29, Wednesday–Tuesday
Spring Commencement	May 3, Saturday

Spring-Summer Term, 1969

Registration for full term and spring half term	May 5–6, Monday–Tuesday
Classes begin	May 7, Wednesday
Memorial Day, a holiday	May 30, Friday
Examination period, spring half term	June 26–27, Thursday–Friday
Spring half term ends	June 27, Friday
Registration for summer half term	June 30–July 1, Monday–Tuesday
Summer half term begins	July 2, Wednesday
Independence Day, a holiday	July 4, Friday
Examination period for full term and summer half term	August 22–23, Friday–Saturday
Full term and summer half term end	August 23, Saturday
Summer Commencement	August 10, Sunday

This calendar is subject to change without notice

College of Engineering

Robben W. Fleming, B.A., LL.B., LL.D., *President of the University*
Marvin L. Niehuss, LL.B., *Executive Vice-President of the University*
Allan F. Smith, A.B.Ed., S.J.D., *Vice-President for Academic Affairs*
Gordon J. Van Wylen, Sc.D., *Dean of the College of Engineering*
Joe G. Eisley, Ph.D., *Associate Dean of the College of Engineering*
Hansford W. Farris, Ph.D., *Associate Dean of the College of Engineering*
Arlen R. Hellwarth, M.S., *Associate Dean and Secretary of the College of Engineering*
Norman R. Scott, 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*
Robert H. Hoisington, M.S., *Assistant Dean of the College of Engineering*
Raymond E. Carroll, B.A., *Assistant to the Dean*
Harold H. Harger, B.A., *Assistant to the Dean*
Alfred W. Lipphart, B.S.E. (Ae.E.), LL.B., *Assistant to the Dean*
Ira K. McAdam, B.S.E. (M.E.), *Assistant to the Dean*
James R. Packard, M.A., *Assistant to the Dean*
John G. Young, B.S.E. (M.E.), *Assistant to the Dean*

General Information

> "Engineering is the profession in which a knowledge of the mathematical and natural sciences gained by study, experience, and practice is applied with judgment to develop ways to utilize, economically, the materials and forces of nature for the benefit of mankind."—Engineers' Council for Professional Development.

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 service. 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 over a period of approximately four years leads to a bachelor's degree. Thirteen programs are offered that lead to the degree Bachelor of Science in Engineering, and two to the degree Bachelor of Science: these are identified as B.S.E., and B.S. respectively in the Contents, page 3.

By careful planning, an additional bachelor's degree (B.S. or A.B.) can be earned in the College of Literature, Science, and the Arts in approximately one year beyond the time required for any one of the degrees referred to above. Refer to Undergraduate Programs, page 41.

History

The College of Engineering observed the centennial of engineering education at The University of Michigan in 1953-54. In 1857, when the first engineering degree was awarded, there were but a few colleges providing opportunities for study leading to this degree; scientific instruction in engineering was first established at West Point in 1802 followed by instruction at Rensselaer which granted the first degrees in Civil Engineering in 1835 in the United States.

As early as 1852, President Henry P. Tappan of the University proposed "a scientific course parallel to the classical course" containing "besides other branches, Civil Engineering, Astronomy with the use of an observatory, the application of chemistry and other sciences to agriculture, and the industrial arts generally." The early curriculum included mathematics, graphics, physics, natural science, elements of astronomy, language, philosophy, and engineering subjects including plain geodetics, railroad and mining surveying, leveling, nature and strength of materials, theory of construction, architecture, machines (particularly the steam engine and the locomotive), and motors, particularly steam and water.

Upon completion of the first four-year curriculum offered at the University, two students were granted first degrees in Civil Engineering in 1860. Today approximately 600 students graduate annually with bachelor's degrees. The opportunities for study have expanded to the point that students may select from about 600 engineering courses.

In the fall of 1967, approximately 3,260 undergraduate students (with 800 entering for first time from high school) and 1,300 graduate students were enrolled in engineering. The total enrollment of the University on the Ann Arbor Campus is over 30,000.

The staff of the College of Engineering consists of 350 engineering instructors; this does not include those who teach mathematics, chemistry, physics, and those elective subjects taken in other colleges.

The University is located in Ann Arbor, a city of 75,000 population located within forty miles from the heart of Detroit, and adjacent to one of

* 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.

the country's largest industrial communities with continually expanding needs for engineering facilities and services.

Accreditation

The following degree programs offered on the Ann Arbor Campus have been accredited by Engineers' Council for Professional Development: Aerospace, Chemical, Civil, Electrical, Engineering Mechanics, Industrial, Materials, Mechanical, Metallurgical, Naval Architecture and Marine Engineering, Physics, Sanitary (first degree M.S.E.), and Science.

Facilities

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

The offices and facilities used for instruction and research in engineering are located mostly in the following buildings on the Central and North Campuses:

- West Engineering Building
- East Engineering Building
- Aerospace Engineering Laboratories
- Automotive Engineering Laboratory
- George Granger Brown Laboratories
- Institute of Science and Technology Building
- Magnetofluiddynamics Laboratory
- Mortimer E. Cooley Building
- National Aeronautics and Space Administration Building
- Phoenix Memorial Laboratory with nuclear reactor

Additional research facilities are located at Willow Run Laboratories, 16 miles from the Central Campus, and at several Ann Arbor locations.

The description of each of the undergraduate degree programs includes a reference to the facilities for the respective programs.

The **Computing Center** provides the University community with central digital computing facilities for use in over 300 educational and research programs. Every student may expect to become familiar with the theory and application of modern computing methods during his course of study. The IBM System 1360 model 67 complex with its supporting Time Sharing System software permits on-line batch processing of data in addition to remote real time access through a large variety of terminal devices. Problems may be transmitted to the central machine from remote graphical cathode ray tube displays, small local computers in addition to several kinds of typewriter-like terminals operating under time sharing.

The **Engineering-Transportation Library,** located on the third and fourth floors of the Undergraduate Library, is one of the more than twenty divisional libraries in the University Library system. Its collection of approximately 300,000 volumes covers all fields of engineering except Nuclear Engineering. The library subscribes to almost 1,000 periodicals and maintains large collections of technical reports, and government documents.

The **Phoenix Library**, located in the Phoenix Memorial Laboratory on North Campus, contains an AEC depository collection of approximately 73,000 reports as well as almost 42,000 volumes on atomic energy.

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.

Cooperative Work-Study Program

In certain fields a desirable application of theory through experience is available, to a limited extent, by combining work with engineering study. To be eligible for acceptance in a cooperative program in industry a student normally completes 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 terms 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 cooperative program, he is expected to continue in it until he graduates or leaves the University.

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

Some upperclass students at the Ann Arbor Campus take advantage of a work-study opportunity through employment as a technician on one of the large number of research projects generally available at the University or in near-by research laboratories. In this case, the student lightens his academic load while working part-time. Also summer employment opportunities provide experiences similar to those claimed for the formal cooperative plan.

Dearborn Campus

The Dearborn Campus, an integral part of the University of Michigan, offers a full-fledged cooperative program in electrical, industrial, and 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 48124.

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 announcement of openings received by mail, and the providing of career and placement information through counseling and published material.

Summer and other short-term training positions in industry are also offered by many employers, especially to students who have completed at least three years of an engineering program. The placement service provides all possible assistance in this area, since such experience is generally considered to be a valuable adjunct to formal technical education.

Meetings for students are conducted by the placement service at the beginning of the fall and winter terms 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.

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 engineer-in-training examination as the first step toward 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 practice 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.

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. University student organizations such as orchestras, bands, glee club, sports groups, and other clubs provide excellent opportunities for self-development.

The College believes that participation by each student in an appropriate activity associated with the College provides an important contribution to his professional development. Some employers look with favor on significant achievements outside the class room in the belief that activities constitute an important part of the University life. Engineering students are encouraged to take an active part in them after they have satisfied their scholastic time budget.

Alpha Pi Mu, national industrial engineering honor society

American Chemical Society, student chapter

American Institute of Aeronautics and Astronautics

American Institute of Chemical Engineers, student chapter

American Institute of Industrial Engineers

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, with affiliated committees

Eta Kappa Nu, national electrical enginering honor society

Honor Council

Institute of Electrical and Electronics Engineers, student branch

Meteorology and Oceanography Student Council

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

Pershing Rifles

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

Tau Beta Pi, national engineering honor society

Triangles, junior honor society

University of Michigan Amateur Radio Club

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 University scholarships, fellowships, and prizes, as well as loan funds, are available to qualified 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. In keeping with University practice and policy, financial assistance is available to qualified students regardless of race, color, or creed.

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 for Engineering College scholarships are accepted during the periods of January 17 to February 15 and September 26 to October 17. Application forms can be obtained at the Dean's Office, 255 West Engineering Building. Scholarship Office tel. 763-2180.

A number of qualified seniors are employed each term as student assistants for assigned work in 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. Contact the appropriate departmental secretary for information.

Veterans and Social Security Benefits

Educational benefits are available to students who qualify under the several Public Laws providing benefits for veterans, and to orphans or children of a disabled parent who qualify under the Social Security Law. Questions may be referred to Assistant Dean's Office.

Selective Service Regulations

In general, each student is responsible for maintaining up-to-date information with his local Selective Service Board. The University will supplement this information on request of the student, and will notify the student's Board when status of enrollment changes. Questions may be referred to Assistant Dean's Office.

Fees, Deposit, and Indebtedness

The following fees for the academic full terms (fall, winter, spring-summer), and for the half terms (spring half, or summer half) are subject to change without notice. Any question on residence regulations may be referred to the Assistant Dean.

Academic Full Term Fees

Undergraduate			*Graduate*		
Credit Hours	*Michigan Residents*	*Non-Residents*	*Credit Hours*	*Michigan Residents*	*Non-Residents*
1	$48	$165	1	$65	$205
2	66	225	2	90	280
3	84	285	3	115	355
4	102	345	4	140	430
5	120	405	5	165	505
6	138	465	6	190	580
7	156	525	7	215	655
8	174	585	8 or more	230	700
9	192	645			
10 or more	210	650			

Divided Term Fees (Spring Half Term or Summer Half Term)

Undergraduate			*Graduate*		
Credit Hours	*Michigan Residents*	*Non-Residents*	*Credit Hours*	*Michigan Residents*	*Non-Residents*
1	$36	$120	1	$50	$150
2	54	180	2	75	225
3	72	240	3	100	300
4	90	300	4 or more	115	350
5 or more	105	325			

Term fees are payable prior to registration, at registration, or in installments during the term. The number and dates of the installments will be announced in advance of each term. Requirements on an enrollment deposit are stated below.

Students are urged to provide themselves with money orders or bank drafts to cover term fees. For the convenience of students, the Cashier's Office will cash or accept, in payment of term 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.

Fees are the student's contribution to the cost of class instruction, library services, physical education privileges, and membership in the University Activities Center. In addition to the term fees, some courses such as chemistry and engineering graphics have a laboratory or materials fee.

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 $30) *must* be paid at the time of registration. This coverage extends for a full twelve months.

Residence Halls. Unmarried freshmen are required to live in University Residence Halls unless living at home. Room and board in the residence halls cost approximately $525 per term.

Enrollment Deposit. In order to manage its over-all enrollment more efficiently and to guarantee each newly admitted student a place in that enrollment, the University requires a non-refundable $50 deposit; this will apply against his fees upon registration for the term for which he has been admitted. Information will be supplied at the time of admission.

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, no official grade report or transcript of academic record will be issued, nor will future registration be permitted.

Admission

Applicants for admission should be at least sixteen years of age and officially recommended graduates of accredited high schools. Qualified applicants are considered without regard to race, color, or creed. 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 for the fall term should be submitted by the preceding February 1 to receive equal consideration with other qualified applicants. However, qualified students who seek admission after this date will always be given consideration provided places are still available. 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 completion of his high school program with grades equal to those on which admission was granted.

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 assure 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	
Three units are required: four recommended	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 should be removed before the anticipated date of entrance, particularly in mathematics. When conditions warrant such action, provisional admission may be granted if not more than two units are lacking.

Looking Forward to 1972.

The following admission requirements will be effective for students entering as freshmen in 1972:

Subject	*Number of Units*
English	4
(A student who presents 3 units may apply one unit of foreign language to complete the 4 units.)	
Mathematics	4
To consist of a minimum of 2 units of algebra; 1 unit of geometry; ½ unit of trigonometry; ½ unit of analytic geometry or advanced topics.	
Chemistry	1
Physics	1
Academic Electives	4
Two units of foreign language are recommended; remaining units from subjects such as history, economics, and biological science.	
Units to make up the necessary 16 units	2
May include any subjects listed above or any other subjects counted toward graduation by the high school such as art, music, business, shop, mechanical drawing, and computer programming.	
Total	16

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. See profile below.

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). See profile below.

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 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, or to Box 1025, Berkeley 1, California.

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.

Profile of Freshman Class

The following is a profile of the 1967 freshman engineering class which experience shows should represent closely the profile of the next incoming group.

A prospective freshman is advised to take this into account with his high school counselor when considering admission to this college.

High School Rank		*College Board Scholastic Aptitude Test Scores*		
Of 800 freshmen	*Rank in high school class*	*Range*	*Mathematical*	*Verbal*
58% were in	top 10%	Median	663	559
25% were in	second 10%	700-800	29.8%	3.2%
11% were in	third 10%	650-699	27.3%	8.7%
6% were below	top 30%	600-649	23.5%	17.6%
		550-599	12.8%	25.2%
		500-549	4.9%	21.8%
		below 500	1.9%	23.6%

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, or to Box 1025, Berkeley 1, California.

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 graduation. 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.

A male student transferring at the junior level has the opportunity to attain a commission in the Army, Navy, or Air Force by enrolling in the respective ROTC Advanced Course. As early as possible, he should contact the unit on the campus to make the necessary arrangements for basic training during the summer. See ROTC section for details.

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 elective courses in humanities and social sciences; he may also be able to elect 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, Andrews University, Calvin College, Central Michigan University, Eastern Michigan University, Grand Valley State College, Hope 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.

For a combined program with the College of Literature, Science, and the Arts of the University, refer to Undergraduate Degree Programs, pages 44-45.

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 terms enrollment and a minimum of 30 hours credit, the student will be recommended for the appropriate degree.

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 credit that will be allowed toward a bachelor's 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 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 hours transferred. (See under Class Standing).

In general, only those courses that contribute to the completion of the student's degree requirements will be recorded on his academic record for this college. Grades earned are not recorded, and the student's grade-point average is determined solely by the grades earned while he is enrolled in this College. This applies also to students transferring from another school or college of the University. 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 degree 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. A student regularly enrolled in another college is permitted to elect appropriate college courses as a guest student. He must apply for enrollment before the beginning of each term he desires 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 also 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. (TOEFL is the only acceptable substitute for the test.)

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 48104.

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 term 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. To increase the probability of success, a student who observes any irregularity in his adjustment or progress should report immediately to his program adviser or to the Assistant Dean's office.

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

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.

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.

A student who experiences in his first term any difficulty in making a satisfactory adjustment to his studies in this College should report immediately to his freshman counselor or program adviser, or to the Assistant Dean's Office. He must assume a responsibility for his own welfare and for planning his progress toward his educational goal.

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 term 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. Freshmen counselors, consisting of a group of well-qualified instructors from the professional departments are available in a central freshman counseling office for interviews throughout the fall and winter terms.

Each entering freshman meets with a counselor to determine his schedule of courses for his first term. This is covered in detail in the section "Planning the Student's Program."

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 on questions relating to their career plans and academic programs and to discuss any matter of interest or concern. Midterm is a particularly appropriate time to examine progress.

Program Adviser. At the beginning of each of the statements on the fifteen 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 freshman 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.

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 few 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

Students vary in their abilities and interests, in their level of achievement, and in their high school or pre-engineering preparation. Considerable variety and flexibility are provided to plan each student's schedule so that he may reach graduation as efficiently as possible. The objective is to place each new student in courses commensurate with his previous preparation and his ability, exercising care not to include any courses which the student is judged to be unable to handle successfully.

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.

Freshman and Sophomore Program

For each freshman, the counselor will use the record of courses taken in high school, the record of performance, and the results of various tests to help plan his courses for his first term. A student with an admission deficiency is required to remove it during his first year, unless granted an extension of time by the Assistant Dean.

Studies of the First Year. The schedules for the first two terms will generally include courses from among the following subjects: mathematics, English, engineering graphics, chemistry, physics, and an elective subject in a technical or 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, military, and naval science leading to a commission on graduation. Enrollment is voluntary (see Conditions of Enrollment under Reserve Officers Training Corps). If elected, hours of credit and the grades earned will be recorded and included in the computation of grade-point averages. The only hours of credit 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 Term	*Hours Credit*	*Second Term*		*Hours Credit*
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	2 or 3	2 to 5*
or		Chemistry	4	
Elective	3 or 4	Elective	3 or 4	
Physical Education	0	Physical Education		0
or		*or*		
ROTC	1 or 3	ROTC		1 or 3

Usual combinations of the subjects listed above will result in a term schedule with 15 to 17 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.

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

Studies of the Second Year. A part of the normal schedule for the third and fourth terms consists of the remainder of the Group A courses common to all professional programs.

Third Term	*Hours Credit*	*Fourth Term*	*Hours Credit*
Mathematics 215	4	Mathematics 315†	2
Physics 146	5	Mathematics 316	2

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. A student who needs help in making his selection should attend the group meetings scheduled during the winter term. If he needs additional help, he should consult with his freshman counselor, or with program advisers. During his second term, he should be prepared 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 Bachelor's Degrees. Through careful planning of his course elections throughout his college enrollment, a student with interests in more than one program offered by the College may work for two bachelor's 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. A minimum of 14 credit hours is required for the second degree.

Also available is an opportunity to obtain an additional bachelor's degree in the College of Literature, Science, and the Arts. (See under Requirements for Graduation, paragraph 4 and 5.)

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 usually prescribed for the first term. Generally, a student will take English 112 during the second term and prior to electing courses from Group II. If a student has met the English 112 requirement during the first term, or has been excused from the course on the basis of proficiency, he may elect a course from Group II during the second term. Courses in Group 1-A

† Students electing the Degree in Applied Math. should choose Math. 310 in place of Math. 315.

are also available to freshmen to satisfy part of the requirements for humanities. See page 43.

Students with particularly high aptitudes (as determined by College Board scores) and interests in literature may, with permission, elect Great Books courses toward fulfilling the requirements in English composition, and literature—Group II.

Mathematics. The mathematics sequence of 115, 116, 215, 315, and 316 provides an integrated sequence in college mathematics, sixteen hours credit, that includes analytic geometry, calculus, and elementary differential equations. (Mathematics 315 and 316 may be elected concurrently as Mathematics 216.)

While most freshmen elect Mathematics 115 in their first term, 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*	*Hours Credit*
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

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

Transfer students from other colleges who have completed college algebra, and plain and solid analytic geometry without calculus, normally will be allowed six hours credit and will be required to take Mathematics 213 and 214 (four hours credit each) and Mathematics 316 (two hours credit) to complete the Group A requirements.

Engineering Graphics. A three-hour engineering drawing course, Engineering Graphics 101, is normally scheduled the first year. The several programs vary with respect to additional requirements in engineering graphics. The student should refer to Group B of the program in which he plans to enroll and should consult with his counselor before electing a second graphics course, usually Graphics 104, 2 hours credit.

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

Students who do not qualify for the Unified Science sequence will elect Chemistry 103, 104, or 107 as the beginning chemistry course, as shown in the following outline. Eligibility for Chemistry 104 or 107 depends upon the high school record and the score achieved on a placement test given in the orientation period.

Chemistry 104 is the normal prerequisite for Chemistry 106. Election of Chemistry 106 after completing Chemistry 103 requires special permission.

Those Students Who:	*Elect*	*Hours Credit*
I. Do not have strong backgrounds in chemistry as determined by placement tests given during orientation	Chem. 103 and 105*	8
II. Do have strong backgrounds in chemistry as determined by placement test during orientation	Chem. 104 and 106*	8
III. Do have strong backgrounds in chemistry as determined by placement test during orientation and who wish a single course	Chem. 107	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.

* Under special circumstances students may elect Chemistry 103 and 106 or Chemistry 104 and 105. See prerequisites under course description. A student with a high record in Chemistry 103 or 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 savings of credit hours.

The normal freshman schedule includes Physics 145 in the second term. 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 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 Term:	Math. 185 (4 hours) and Physics 153 (4 hours)
Second Term:	Math. 186 (4 hours) and Chem. 194 (4 hours)
Third Term:	Math. 285 (4 hours) and Chem. 195 (4 hours)
Fourth Term:	Math. elective and 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.

Attention is also called to the availability of Great Books courses under "English" above.

Other Possibilities for the First-Year Schedule. The College is preparing for adjustments in the curriculum and is offering courses in engineering concepts and perspective, computer graphics, and computer techniques particularly appropriate for the freshman year. Any of the courses elected will satisfy some part of the degree requirements.

A student who satisfies his chemistry requirements during his first term and who plans to select a program requiring additional chemistry, should immediately elect an appropriate chemistry course. If he plans to select the chemical or metallurgical engineering program, he may elect Chemical and Metallurgical Engineering 200, three hours.

Acceptable courses in humanities and social sciences may be elected either first or second term that will apply against the requirements in Group B. For example, see English, page 169, Group 1-A.

Language

Although a foreign language is not required for admission nor does it appear in any program requirements except Physics (in this case, 8 hours of modern language), many students enter with the equivalent of college-level work. A student who qualifies for advanced placement credit, either by the Advanced Placement Examination or by examination offered by the University language department may be given credit for the number of hours allowed for his previous study provided he enrolls in one additional language course at the University. This should be elected during the freshman year, if possible. Such hours may be used to satisfy degree requirements in appropriate category of Group B electives on approval of the student's program adviser.

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 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 term 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 placed, he should report immediately to his program adviser.

Rules and Procedures

General Standards of Conduct for Engineering Students

In establishing a standard of student conduct The University of Michigan is committed to the basic principle of entrusting each student with a high degree of freedom to govern his life and conduct while enrolled at the University.

The College of Engineering encourages its students to protect and utilize this freedom with wisdom and good judgment, and to accept and discharge the responsibility inherent to such freedom.

The student is expected to develop his relationships with integrity; to respect the rights and properties of others; to comply with University regulations and public laws; and to live with high standards of personal and social conduct.

The College of Engineering welcomes the participation of students in decision making relevant to their affairs and provides channels of communication, both at the College and department level, for that purpose. To benefit from such activity, each student should recognize his responsibility to his fellow students and to the faculty, and should discharge his duties with the high standards that make such student-college relationships effective and valuable.

The College of Engineering reserves the right to discipline, exclude from participation in relevant activities, or dismiss any student whose conduct or performance it considers unsatisfactory. Such decision will be made only after review by the appropriate student and faculty committees. During this review the student will have full opportunity to present his position. A student also has the right of appeal to the Executive Committee of the College.

The Honor Code of the College (below), bears witness to the deep trust that characterizes the student-faculty relationships in one of the most important aspects of student conduct.

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 high standard of ethics which is essential to a successful engineer and a good citizen. The instructor does not remain in the room during an examination. Each student is placed upon his honor, and is asked to write and sign the following pledge at the end of his examination paper:

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

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

The Honor Council has prepared a booklet, available in the Assistant Dean's office, which explains the principles and operation of the Honor Code.

Independent Study. In general the principles of the Honor Code also apply to homework when the instructor requires the material turned in to be the student's own work. While independent study is recognized as a primary method of effective learning, some students may find that they benefit from studying together and discussing home assignments and laboratory experiments. When any material is turned in for inspection and grading, the students should clearly understand what cooperation between them, if any, is permitted by the instructor. When independent study and performance are expected the deliberate attempt to present as one's own work any material copied from another student or from any source not acknowledged in the report is forbidden. In such cases the instructor may require the signing of the pledge and expect the same high standards of integrity as during examinations; he may report suspected violations.

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 half term 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, Deposit, and Indebtedness.

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 term) 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 excuses for absences from required physical education classes must be presented to the Waterman Gymnasium office for approval; unexcused absences must be made up. Health Service statements will be accepted only for illness of more than 24 hours.

Definitions

Term. A term is a period of enrollment extending over approximately four months, including examinations. Term requirements are equivalent to those of the conventional semester. Schedule, by months, of the University's year-round calendar is as follows:

Name of Term	*Period*	*Identification Used in Description of Courses*
Fall	Sept., Oct., Nov., Dec.	I
Winter	Jan., Feb., Mar., Apr.	II
Spring-Summer	May, June, July, Aug.	III

The Spring-Summer term may be scheduled as two half terms, approximately as follows:

Spring half term	May, June	IIIa
Summer half term	July, Aug.	IIIb

Summer half term is synonymous with the University's Summer Session. In the following rules and procedures, the word "term" also applies to half term (and summer session) unless otherwise indicated.

Credit Hour. A credit hour represents, generally, one hour of recitation or lecture per week for a term, or two for a half term; preparation for each credit hour should require normally two hours of study. Generally, one period of laboratory work is considered equivalent to one hour of credit. "Credit hour" or "hours of credit" as used in this announcement and as reported on the student's academic record are synonymous with "semester hour" or "semester hours credit".

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

Election of Studies

Course Offerings: The appropriate *Announcements,* and the *Time Schedule* prepared for each term will serve the student as a guide in planning each term'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 term of his freshman year and is referred to the appropriate program adviser at the completion of approximately thirty hours of credit. 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.

The transfer of a student who is not in good scholastic standing may depend on satisfying certain conditions agreed to by the program advisers.

Election Considerations. At any time, a student's elections must take into account his preparation (including deficiencies), demonstrated ability and performance, the need for repeating courses, 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. Minimum full schedule is twelve credit hours during a term or six during a half-term.

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

In order to make normal progress toward graduation, a student should average over 15 hours per term. When a student has good reasons for carrying less, he should call this to the attention of his counselor at the time he is planning his elections. If he is required 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 term, 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 (official enrollment).

All students are required to have and use a Social Security number for registration and records purposes.

Completion of both the classification and registration procedures is required before a student has permission to attend any class; failure to do so without approval of the Assistant Dean may be cause for referral to the Discipline Committee.

Change of Classification. After a term has begun, 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.

When a student requests a change from one section to another of the same course, he can make the change official through use of a "change of section" form with the approval of the department or instructors involved.

Dropping a Course. During the first six weeks of a term or first three weeks of a half term, a course may be dropped without record where there is a justifiable and educationally valid reason, and when the student has the approval of his counselor. (Subject to conditions stated under Work Load, above.)

Thereafter, a student must obtain the approval of his program adviser (or the Assistant Dean, for freshmen) to drop a course officially either without record or with grade of E; approval without record will depend on satisfactory evidence of extraordinary circumstances. When considered advisable, the program adviser may discuss the request with the student's instructor.

The grade for any course dropped unofficially will be recorded as U (unapproved drop) and computed as E in the averages.

A student enrolled in an ROTC program must have 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.

When a student requests dropping all courses, his program adviser will refer him to the Assistant Dean's Office to effect withdrawal.

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 43.

A student may elect courses in addition to those required for his degree. He may not register in the College of Engineering and elect courses offered by another college if such elections do not contribute to a goal of a bachelor's degree in this college, 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 term is an essential part of the work of the course; the instructor is required to observe the official final examination schedule established by the University.

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.

See Honor Code for procedures pertaining to examinations.

Grades and Scholastic Standing

Averages. The term grade-point average and the cumulative grade-point average are computed for each student at the end of each term and become part of his academic record. The grades are valued per hour of credit 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	U—Unapproved drop	0 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 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 at the end of each winter term.

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

Grade Reports. Unless withheld for infringement of rules, each term'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.

Good Scholastic Standing. To be in good scholastic standing at the end of any term, a student must have a grade point average of 2.00 or more for the term and a cumulative grade point average of 2.00 or more.

In order to attain a bachelor's degree, a student's final cumulative average must be 2.00 or more as computed from grades earned in all courses elected while enrolled in this College.

Rules Governing Scholastic Standing for Unsatisfactory Performance. Two degrees of scholastic deficiency identify a student's unsatisfactory performance resulting from D, E, or U grades: on probation, and further enrollment withheld.

Scholastic standing is determined by observing grade points earned for hours attempted. When a student's record is such that his grade points are deficient (that is, less than the number required to give him an average of 2.00), scholastic standing will be determined as follows:

Rule 1. On Probation: When a student has a deficiency of 1 to 9 grade points for either his term or cumulative record, he will be on probation. A student on 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. (The rules for repeating courses in which a D grade is earned are given below.)

Rule 2. Further Enrollment Withheld: When a student has a deficiency of ten grade points or more for either his term or cumulative record, his further enrollment will be withheld. (Note exceptions in Rules 3 and 4).
See Rule 5 for Conditions for Reinstatement on Probation.

Rule 3. On Probation: When a first-term student has a deficiency of ten grade points or more for his first term record, he will be on probation; and, in addition to the conditions stated under Rule 1, he must arrange an interview with the Committee on Scholastic Standing.

Rule 4. On Probation: When a student who has never been on probation has a deficiency of ten grade points or more for his most recent term but has a cumulative average of 2.00 or more, he will be on probation; and, in addition to the conditions stated under Rule 1, he must arrange an interview with the Committee on Scholastic Standing.

Rule 5. Reinstatement on Probation: When a student's further enrollment is withheld, he has the privilege of presenting the associated circumstances for his unsatisfactory performance to the faculty Committee on Scholastic Standing in a manner specified by the committee, normally in an interview. If the student can show a satisfactory reason for his low record, and if he can present sufficient and convincing evidence why he should be given another opportunity, the committee may reinstate him on probation.

The committee may specify the credit-hour load, and the minimum improvement rate to continue his enrollment beyond the term for which the reinstatement is effective. When a student has been reinstated, he will be required to consult the Committee on Scholastic Standing after the completion of each term until his performance restores him to good standing (See Rule 8).

Rule 6. Further Enrollment Withheld: When a student fails to meet the conditions under Rule 5, his further enrollment will be withheld.

Rule 7. Further Enrollment Withheld: When a student's performance is such that he is on probation for the third time (or more), counting all rules that place or reinstate him on probation, his further enrollment will be withheld.

Rule 8. Restored to Good Standing: When a student's performance for a term during which he has been on probation has improved so that both his term and cumulative averages are 2.00 or more, he will be restored to good standing.

Half-term. The rules above will apply to a single half term; if the student enrolls in both spring and summer half terms, the rules will apply to the combined results of both.

D Grades. While a grade of D is passing, it is not considered satisfactory performance and at any time a student earns a grade of D, he should consult his counselor before continuing his studies another term.

A student on probation must repeat as soon as possible each course in 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 course in which he earned a D grade provided he does so during the next two terms he is enrolled. As a general principle, any student is well-advised to repeat such a course 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. A course required by the student's program must be repeated as soon as possible.

Incompletes. When a student is prevented by illness, or by any other cause beyond his control from taking an examination or from completing any vital part of a course, or if credit in a course is temporarily withheld for good reason, the mark "I" may be reported to indicate the course has not been completed. This mark should be used only when there is a good probability that the student can complete the course with a grade of D or better without enrolling in the class again.

No qualifying grade will be recorded on the student's academic record. The "I" mark will not be used in computing either the term or cumulative averages. His scholastic standing at the end of any term is determined on the basis of work completed or graded.

In order that credit may be allowed, the required work must be completed before the end of the eighth week of the first term (not including half terms) that the student is enrolled after the term in which the "I" mark was recorded, unless an extension is approved in advance by the instructor and the Assistant Dean. If the student does not meet this requirement, the "I" mark will be changed to E by the Records Office, averages computed, and his scholastic standing redetermined. If, as a result, further enrollment is withheld by the Rules Governing Scholastic Standing, the student will be permitted to complete the term but may continue for another term only by action of the Committee on Scholastic Standing.

A student who finishes a term with more than one "I" mark must report to the Assistant Dean for permission to enroll for an ensuing term.

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 U (unapproved drop), or N (no report). 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 cumulative average, but the hours of credit are used only once in computing the hours accumulated towards his degree.

Class Standing

The number of hours achieved toward graduation at the close of the term in which a student was most recently enrolled will be used to determine his class standing for statistical purposes. Questions concerning class-level designations should be referred to the Assitant Dean's Office.

	Underclassmen	
Class		*Hours*
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 applicable to his elected program. When, in the opinion of his program adviser, there is a reasonable expectancy that a transfer student on a prescribed program will graduate within one year, he will be classified as a senior.

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 term requires the approval of the Assistant Dean. A student under twenty-one may be required to present evidence of parent's approval.

After the sixth week of a term, or third for a half term, a student requesting withdrawal without record must present evidence of extraordinary circumstances. In any case, the Assistant Dean may specify the conditions for readmission.

For regulations on refunds, refer to the *General Information* bulletin under Fees and Expenses.

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 student's enrollment has been interrupted for two consecutive terms, 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 whose further enrollment has been withheld must first be reinstated on probation by the Committee on Scholastic Standing.

Honors

The Dean's List

Degree candidates who elect courses and complete a minimum of 12 credit hours (6 for a half-term) and earn a 3.50 term average or better, attain the distinction of the Dean's Honor List for the term.

Convocations

Annually, those students who have earned distinguished academic records participate in the University's Honors Convocation. Also the College gives special recognition to students with high scholastic achievement and with records of service to the College and its student organizations.

Society Recognition

Distinguished scholarship and services to the College are also recognized by election to any of a number of honor societies that are included with the list of organizations under Extracurricular Opportunities.

Recognition on Diploma

A student graduating with at least 65 hours of credit which have been completed while enrolled in this College (or as directed by the Executive Committee) will be recommended for a degree (and for each degree, if more than one) with recognition on his diploma if he qualifies according to the following:

Grade Point Average	Distinction
3.20–3.49	cum laude
3.50–3.74	magna cum laude
3.75–4.00	summa cum laude

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. A student completing the requirements for more than one degree must file an application for each. This should be done early in the term in which the student is reasonably certain of completing his work for the degree. If he does not complete his work in that term, it will be necessary for him to renew his application early in the succeeding term.

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

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 bachelor's 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 credit 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 cumulative 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 credit hours or more in the College of Engineering, Ann Arbor campus, prior to the beginning of his last 30 hours required for graduation, may elect 6 of the last 30 hours at another recognized college. All other students must complete their last 30 credit 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 14 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 cumulative grade-point average requirement of 2.00 or more.
5. To obtain an additional bachelor's degree (B.S. or A.B.) in the College of Literature, Science, and the Arts, a student must complete at least 90 credit hours in the College of Literature, Science, and the Arts; satisfy the distribution requirements and the concentration requirements of the College of Literature, Science, and the Arts; satisfy the Group A and B requirements of the College of Engineering; and meet the scholastic requirements of each college. He must also make applications for diplomas to each college. For details refer to page 44.

Undergraduate Degree Programs

Each of the fifteen 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.

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

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 Credit*	*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, 315* and 316
	or	
	12	Math. 185, 186, and 285
Engineering Graphics	3	Eng. Graphics 101
Chemistry	5 or 8	See Chemistry, page 28
Physics	10	Physics 145 and 146
	or	
	8	Physics 153 and 154

* Applied Math. majors should elect Math. 350. See note page 60.

Note—The number of credit 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.

Credit is not granted for work experience.

Group B Subjects

Group B for each program is composed basically of "professional and advanced subjects and electives," consisting of a total of 95 credit hours, that will prepare the student for the particular field of engineering he selects.

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.

Humanities and Social Sciences. To provide a desirable breadth of education, each program in this College specifies a certain number of credit hours of elective courses concerned with human cultures and relationships. Such courses are generally identified in the Group B requirement as English—Groups II and III, literature, economics, and humanities and social sciences. Excepting the courses offered by the Department of English, College of Engineering, these are offered by other colleges or schools in the University.

For those programs in which a requirement of humanities and social sciences is stated without more explicit definition, the requirement may be satisfied from the following: 1) Group II and Group III English courses in the College of Engineering, 2) courses in the College of Architecture and Design whose major emphasis is on the fine arts, 3) courses in the College of Literature, Science, and the Arts in the department of American Studies, Anthropology, Asian Studies, Classical Studies, Economics (except accounting and statistics), Geography (except physical geography), Great Books, History, History of Art, Linguistics (except English as a Foreign Language), Music, Philosophy, Political Science, Psychology, and Sociology, and all departments of Languages and Literature.

Other Electives. Subject to the limitations of his program and to the approval of his program adviser, a student may also 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 such as mathematics, chemistry, physics, astronomy, biology, and the management sciences; and courses in air, military, or naval science.

It is permissible and frequently desirable for a student to elect courses in addition to those required for his degree. Such a plan permits a wide freedom of choice, and an opportunity to explore areas of cultural as well as professional interest. It provides for preparation for continued or advanced study in a selected field, either in engineering and physical sciences, or in other areas such as business administration, law, medicine, or education. The student should have a clear understanding with his program adviser before electing any course in excess of his degree requirement.

Time Requirements for the Bachelor's Degree

The time required to complete a degree program depends on the background, ability, and interests of the individual student. A full-time schedule averaging 14 to 17 hours will allow students to complete their degree requirements in eight to ten terms; e.g. when the degree requirement is 138 credit hours the student must average slightly more than 15 hours per term to complete in nine terms. 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 term as an undergraduate (refer to the *Announcement* of the Horace H. Rackham School of Graduate Studies).

Additional Bachelor's Degrees from College of Literature, Science, and the Arts

Program Advisers: Professor W. C. Bigelow, 4213 East Engineering
Professor R. C. Taylor, 1044 Chemistry Building

Students enrolled in the College of Engineering or the College of Literature, Science, and the Arts who desire broader training and experience than is normally obtained in either college alone may participate in a Combined Degree Program leading to bachelor's degrees in both colleges. The regulations for this program are as follows:

1. Students enrolled in either the College of Engineering or the College of Literature, Science, and the Arts may participate in the Combined Degree Program.
2. A student considering the program should consult one of the program advisers as soon as his interest is firmly established, but preferably no later than during his second term of University work.
3. Admission to the program is subject to approval by the assistant deans and appropriate departmental program advisers in the two colleges. To qualify for admission, a student ordinarily must have completed at least 30 credit hours of work on this campus and have a grade point average of at least 2.40.
4. Once admitted, a student must meet the scholastic standards of both colleges to remain active in the Combined Degree Program; to permit most effective scheduling of the technical courses in the two colleges, he will not be required to meet the time limitations for completion of distribution requirements which are normally applicable to students in the College of Literature, Science, and the Arts.
5. Upon being admitted to the Combined Degree Program, a student must specify his intended field of specialization in each college. Thereafter, the corresponding program adviser in each college (or special counselors designated by the assistant deans), and the program advisers for the Combined Degree Program will assist the student in developing a schedule of courses that will effectively and efficiently meet the requirements of the Combined Degree Program.

Program Requirements

Candidates for bachelor's degrees in both the College of Engineering and the College of Literature, Science, and the Arts under the Combined Degree Program must (*a*) satisfy the Group A and Group B requirements of the College of Engineering; (*b*) satisfy the distribution and concentration requirements of the College of Literature, Science, and the Arts, and take a minimum of 90 credit hours of work in that college; and (*c*) meet the scholastic standards of both colleges. These requirements are described in detail in the *Announcements* of the two colleges. Students interested in the Combined Degree Program should become thoroughly familiar with both *Announcements.*

Because of the variety of possible combinations of programs in the two colleges that might be chosen by students under the Combined Degree Program, it is not feasible to attempt to list course requirements in detail. Instead, it is recommended that each student consult with the program advisers for the Combined Degree Program to explore requirements for the particular combination of fields of specialization that is of interest to him.

In general, counselors working with students in the Combined Degree Program will attempt to minimize the total number of courses required by recommending courses which will contribute toward fulfilling requirements in both colleges whenever possible. Thus, many of the courses needed to fulfill the Group A requirements in mathematics, chemistry, and physics in the College of Engineering will contribute toward fulfilling natural science distribution requirements and prerequisites for concentration in fields such as astronomy, chemistry, geology-mineralogy, mathematics, and physics in the College of Literature, Science, and the Arts; many of the concentration cognate courses can be selected from the Group B engineering science courses; likewise, the nontechnical electives and the Group B requirements in literature for the College of Engineering can be selected from among courses taken to fulfill the College of Literature, Science, and the Arts distribution requirements.

In this way, it should be possible for a student carrying an average load of 17 credit hours per term to complete the requirements of the Combined Degree Program in 10 or 11 terms.

Representative Schedule

In an effort to provide the interested student, both freshman and transfer, with a sample schedule, the information for a number of the degree programs includes a representative schedule. This is for informational purposes only and should not be construed to mean that students are required to elect this program in the exact order as printed. It would generally be different for a student electing ROTC.

Transfer students attending a community or liberal arts college and pursuing a pre-engineering degree program, probably could not follow the schedule because of a lack of offerings in their colleges. These students would substitute humanities and social sciences electives for the professional courses listed in the schedule during the sophomore year. Some representative schedules include a spring or summer half term. Students are not required to attend a half term. Most representative schedules indicate a term load of 17 or 18 credit hours. Many students cannot meet the demands of such a heavy schedule and elect fewer hours each term.

Aerospace Engineering

Program Adviser: Professor Buning, 1511 East Engineering

The design of modern aircraft, missiles, and space vehicles involves problems in many branches of engineering and the sciences. The program in aerospace 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 flight vehicles. A sequence of courses in propulsion considers theoretical aspects of aerothermodynamics and applications to jet and rocket motors. A sequence of courses in structural mechanics develops the fundamental equations of solid mechanics and applies them to static and dynamic problems of light weight structures. Another sequence considers the dynamic stability and control of flight vehicles. In the senior year a course in design is provided which draws on the experience gained in many of the earlier courses.

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

Electives are provided which enable the student to broaden his understanding of the various areas of aerospace engineering or to specialize in one of them.

Facilities

The Department of Aerospace Engineering provides laboratories for instruction and research in gasdynamics, guidance and control, and structures. The facilities for studies in gasdynamics include wind tunnels and channels covering wide speed and temperature ranges, as well as special pieces of equipment adapted to the study of specific problems. The information and control laboratory is equipped for studies of the fundamentals of guidance, automatic control, and instrumentation. This laboratory includes a number of electronic differential analyzers for teaching and research. The structures laboratory includes static testing machines and equipment for vibration excitation. Strain-measuring equipment includes strain gages and recording equipment for static or dynamic measurements.

Requirements

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

A. Subjects to be elected or equivalent proficiencies to be demonstrated (see page 42)

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, Descriptive Geometry	2
Econ. 401, Modern Economic Society	4
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. 314, Circuit Analysis and Electronics	3
Elec. Eng. 315, Circuit Analysis and Electronics Laboratory	1

	Hours
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 or Aero. Eng. 483	4
Electives in the Humanities and Social Sciences	12
Electives*	11
Total Hours in Group B	95

Representative Schedule (see page 45)

For studies of the first year, see page 25.

Third Term	*Hours*
Math. 215	4
Physics 146	5
Aero. Eng. 200	2
Eng. Mech. 208	3
Elective	3
	17

Fourth Term	*Hours*
Math. 216	4
Chem.-Met. Eng. 250	3
Eng. Mech. 210	4
Mech. Eng. 335	3
Elective	3
	17

Half Term	
Elective	3
English, Group II	2
Eng. Mech. 212	1
	6

Fifth Term	
Math. 450	4
Aero. Eng. 320	4
Eng. Mech. 343	3
Elec. Eng. 314	3
Elec. Eng. 315	1
Elective	2
	17

Sixth Term	
Aero. Eng. 314	4
Aero. Eng. 330	3
Aero. Eng. 420	4
Aero. Eng. 441	4
Elective	2
	17

Seventh Term	
Aero. Eng. 430	4
Aero. Eng. 414	4
Econ. 401	4
Electives	4
	16

Eighth Term	
Aero. Eng. 471	4
Aero. Eng. 481 or 483	4
Electives	6
English, Group III	2
	16

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

Chemical Engineering

Program Adviser: Associate Professor J. S. Schultz, 2020 East Engineering

The degree program in Chemical Engineering was established in 1898 at The University of Michigan, one of four schools to introduce the profession in the United States in the last decade of the nineteenth century. The Michigan Student Chapter of the American Institute of Chemical Engineers is the first established by that professional society.

Chemical Engineering, of all branches of engineering, is the one most strongly and broadly based upon physical and life sciences. It has been defined as ". . . that portion of the field of engineering where materials are made to undergo a change of composition, energy content, or state of aggregation." Because of his broad and fundamental education, the chemical engineer can contribute to society in many functions, such as pure research, development, plant operation, and corporate or government administration. The elective freedom of the program allows a student to develop his individual abilities and interests.

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 are some areas of specialization that are available to the student in a regular chemical engineering program.

Biochemical. The combination of biological and chemical reactions to produce antibiotics, frozen foods, fermented products, vaccines, and life support systems in manned space vehicles. Chem.-Met. Eng. 434, 484, 485, 548, and 584.

Electrochemical and Corrosion. The study of electrochemical processes as they relate to energy conversion (batteries and fuel cells), electrosynthesis, electroplating, and corrosion. Corrosion and corrosion control are viewed in terms of materials selection and environmental effects. Chem.-Met. Eng. 510 and 573.

Electronic Materials. The design, preparation, and properties of materials that find application in the electronics industry. Chem.-Met. Eng. 553; 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.

Information and Control. 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; Info. and Cont. Eng. 510, 570.

Machine Computation. The application of electronic computers to the solution of engineering problems. Chem.-Met. Eng. 501; Math. 404, 473, 474; Info. and Cont. 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. 351, 371, 450, 451, 472, 479, 560; Eng. Mech. 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. 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. 400, 411, or 311, 312, 441, 471 *et seq.*

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. 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.

Pollution. The application of chemical engineering operations and technology to the prevention, control and abatement of pollution in the air, water and process wastes. Chem.-Met. Eng. 434, 439, 484, 485.

Systems. The methods of combining individual operations into a working whole with a maximum of efficiency and optimization. Chem.-Met. Eng. 446, 481, 581; Info. and Cont. Eng. 570; Math. 448; Ind. Eng. 472.

Facilities

The facilities located in the East Engineering Building include a cast metals laboratory; metalworking, welding, heat-treating, spectrographic (mass, infrared, ultra-violet, etc.) and metallographic laboratories; an X-ray laboratory for radiography and diffraction studies; electron microscopes; an electron microprobe X-ray analyzer; chemical, high-pressure, process dynamics, polymer, semiconductor, plasma, liquid metal, biochemical engineering, electrochemistry, corrosion, and thermodynamics laboratories; and in Fluids Engineering Laboratory, equipment for heat transfer large scale operations, analog computation, process simulation and research.

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, each 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.

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.

A. Subjects to be elected or equivalent proficiencies to be demonstrated (see page 42)
(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. 225, 226, 227, 265, 266, and 346, or Chem. 195, 225, 226, 227, 468, and 469, or equivalent	20
An electronic computer course such as Math. 273	2

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 hours of literature 14
   (See under English, and the *Announcement* of the College of Literature, Science, and the Arts for courses in these fields.)
2. Electives in law, economics, and business administration 6
   (Typical electives are: Econ. 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).
3. Electives in engineering science and analysis, such as mechanics of solids and fluids, network analysis, electronics, systems, energy conversion, electromagnetics, and thermodynamics 13
   (Typical electives are Eng. Mech. 208, 210, 218, 310, 319, 324, 326, 343, 345, 412, 422, and 527; Elec. Eng. 210, 215, 220, 310, 314, 315, 320, 337, and 419; Mech. Eng. 421, 432, 437, and 471; Chem.-Met. Eng. 430, 434, 450, 470, 472, and 560; Info. and Cont. Eng. 510, 530, and 570; Nuc. Eng. 400 and 411.)
4. Electives in advanced science and mathematics 7
   (Typical electives are: Math. 404, 447, 448, 450, and 552; Chem. 403, 425, 447, 481, 482, and 538; Physics 305, 406, 411, 418, 453, 455, 456, 457, and 463; Zool. 101, 106.)
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. 400, 430, 439, 445, 446, 450, 451, 460, 479, 480, 481, 484, 485, 490, 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 (see page 45)

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

First Term	*Hours*	*Second Term*	*Hours*
English 111	3	English 112	2
Eng. Graphics 101	3	English 121	1
Chem. 107	5	Physics 145	5
Math. 115	4	Math. 116	4
		Chem. 225	3
	15		15

Third Term	*Hours*	*Fourth Term*	*Hours*
Physics 146	5	Math. 273	2
Math. 215	4	Math. 216	4
Chem. 226	3	Chem. 265	4
Chem. 227	2	Chem.-Met. Eng. 230	5
Chem.-Met. Eng. 200	3	(2) Bus. Ad. 305	3
	17		18

Fifth Term		*Sixth Term*	
Chem.-Met. Eng. 341	3	Chem.-Met. Eng. 342	4
Chem. 346	4	Chem.-Met. Eng. 350	3
Chem. 266	4	(3) Eng. Mech. 422	3
(3) Elec. Eng. 314	3	(3) Elec. Eng. 419	2
(3) Elec. Eng. 315	1	(4) Math. 404	3
(1) Literature	2	(1) Literature	2
	17		17

Seventh Term		*Eighth Term*	
Chem.-Met. Eng 343	4	(5) Chem.-Met. Eng. 460	3
(5) Chem.-Met. Eng. 479	3	(5) Chem.-Met. Eng. 480	3
(2) Econ.	3	(5) Chem.-Met. Eng. 481	3
(1) Humanities	4	(4) Adv. Math.	3
(3) Eng. Mech. 310	4	(1) Humanities	6
	18		18

Biochemical Engineering

Adviser: Professor L. L. Kempe, 4209 East Engineering

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, tooth-hardening chemicals, insecticides, potable water from the sea, detergents, algae in space vehicles, prosthetic metals, food yeast from industrial wastes, and synthetic foods.

Electives adapted for the program in biochemical engineering are: Group 3, Chem.-Met. Eng. 434 and 584; Group 4, Chem. 228; Zool. 101; Group 5, Chem.-Met. Eng. 484, 485, and 548.

Combined Programs

Chemical, Materials, and Metallurgical Engineering

Combined degrees may be obtained in chemical engineering and materials engineering, or chemical engineering and metallurgical engineering. A combined program is not recommended in metallurgical engineering and materials engineering because of their similarity.

Chemical engineering students who choose a second degree in metallurgical engineering will take a minimum of fourteen additional hours in the field of process, physical, and mechanical metallurgy. Those who choose materials engineering as a second degree will take at least fourteen additional hours in physical metallurgy, physical ceramics, and polymers.

Students in metallurgical or materials engineering who wish a second degree in chemical engineering must elect a minimum of fourteen additional hours in chemical engineering subjects. These must include Chem.-Met. Eng. 342 and 343, and any others chosen from Elective Group 5 in professional chemical engineering.

Civil Engineering

Program Adviser: Professor Harris, 302 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 many other facilities necessary for public works and industrial development. They are responsible for the safe, economical and efficient operation of many of the above facilities. 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 Engineering. 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 Engineering. Location, design, construction, and maintenance of various types of roads and streets, including materials, surveys, plans, specifications, economics, financing, and administration.

Hydraulic Engineering. 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.

Municipal Engineering. The design, construction, maintenance, and management of the water, wastes, and transportation systems of the urban population along with consideration of the many other factors which affect the urban environment so as to maintain safe and wholesome physical conditions within the city.

Sanitary Engineer. 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.

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

Structural Engineering. 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 and Traffic Engineering. The planning, geometric design, and operation of transportation facilities and terminals. Includes financing, economic analysis, and administration as appropriate.

Water Resources Engineering. (See page 108).

Facilities

The Civil Engineering Department has its departmental offices in the West Engineering Building. The laboratories for Sanitary Engineering and Structural Engineering are also located there. Equipment is available for both teaching and research in those laboratories.

The East Engineering Building houses the highway and soil mechanics laboratories of the Michigan Department of State Highways which are used for instruction by the department.

The Fluids Engineering Laboratory on the North Campus houses the hydraulic engineering laboratory and the soil dynamics laboratory. The lake hydraulics laboratory, which is equipped with a large wave tank, wave-making machine, and the instruments required for the study of problems arising from the action of water along shores is located in the east wing of this building.

The Automotive Engineering Laboratory houses the geodetic engineering instrument room and computation laboratory.

A concrete research laboratory, established to study new developments in concretes, is located in a building at the Willow Run Airport.

Requirements

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

A. Subjects to be elected or equivalent proficiencies to be demonstrated (see *page 42)*
B. Professional and advanced subjects and electives

	Hours
Chem.-Met. Eng. 250, Principles of Engineering Materials	3
English, Groups II and III	4
Eng. Graphics 104, Descriptive Geometry	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	2
Advanced Mathematics	3
Elec. Eng. 314, Circuit Analysis and Electronics	3
Elec. Eng. 315, Circuit Analysis and Electronics Laboratory	1
Mech. Eng. 333, Thermodynamics	3
Civ. Eng. 262, 263, Geodetic Engineering	7
Civ. Eng. 312, Theory of Structures	3
Civ. Eng. 313, Elementary Design of Structures	2
Civ. Eng. 350, Concrete Mixtures	1
Civ. Eng. 400, Contracts and Specifications	2
Civ. Eng. 415, Reinforced Concrete	3
Civ. Eng. 420, Hydrology I	2
Civ. Eng. 421, Hydraulics	2
Civ. Eng. 445, Engineering Properties of Soil	3
Civ. Eng. 470, Transportation Engineering	3
Civ. Eng. 480, Water Supply and Treatment	3
Civ. Eng. 481, Sewerage and Sewage Treatment	2
Geol. 218, Geology for Engineers	3
Econ. 401, Modern Economic Society	4
Humanities and social sciences (see below)	7
Technical option group (see below)	9
Technical electives* (see below)	4
Total hours in Group B	95

The electives in humanities and social sciences are to be approved courses in such fields as economics, history, law, literature, modern languages, 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: Professor Harris
2. Geodetic Engineering—Adviser: Professor Berry
3. Highway Engineering—Adviser: Associate Professor Cortright
4. Hydraulic Engineering—Adviser: Professor Brater
5. Municipal Engineering—Adviser: Associate Professor Glysson
6. Sanitary Engineering—Adviser: Professor Borchardt
7. Soils Engineering—Adviser: Professor Richart
8. Structural Engineering—Adviser: Associate Professor Rumman

* A maximum of 3 hours of advanced air, military, or naval science (300 and 400 series) may be used as electives in this group.

9. Transportation and Traffic Engineering—Adviser: Associate Professor Cleveland
10. Water Resources Engineering—Adviser: Associate Professor Weber

Technical electives will consist of approved subjects selected by the student in conference with his adviser to meet the individual needs of the student. Ordinarily these will be advanced courses in one of the branches of engineering, in mathematics, or in one of the natural sciences.

Representative Schedule (See page 45)

First Term	*Hours*	*Second Term*	*Hours*
Math. 115	4	Math. 116	4
Chem. 104	4	Physics 145	5
Eng. Graphics 101	3	English 112	2
English 111	3	Chem. 106	4
English 121	1		
	15		15

Third Term		*Fourth Term*	
Math. 215	4	Math. 315	2
Math. 273	2	Math. 316	2
Physics 146	5	Eng. Graph. 104	2
Eng. Mech. 208	3	Eng. Mech. 210	4
Civ. Eng. 262	3	Eng. Mech. 212	1
Civ. Eng. 350	1	Geol. 218	3
		Civ. Eng. 263	4
	18		18

Half Term	
Civ. Eng. 312	3
Eng. Mech. 343	3
	6

Fifth Term		*Sixth Term*	
Eng. Mech. 324	3	Advanced Math.	3
Chem.-Met. Eng. 250	3	Civ. Eng. 415	3
English, Group II	2	Civ. Eng. 421	2
Mech. Eng. 333	3	Civ. Eng. 470	3
Civ. Eng. 420	2	Civ. Eng. 480	3
Civ. Eng. 445	3	Options and electives	3
	16		17

Seventh Term		*Eighth Term*	
Elec. Eng. 314	3	English, Group III	2
Elec. Eng. 315	1	Econ. 401	4
Civ. Eng. 313	2	Civ. Eng. 400	2
Civ. Eng. 481	2	Options and electives	8
Options and electives	9		
	17		16

Electrical Engineering

Program Advisers: Professor R. K. Brown, 4512 East Engineering, Professor L. F. Kazda, 2526 East Engineering; Professor J. C. Mouzon, 2515 East Engineering

Electrical engineers concern themselves with the following areas as applied to the control and processing of information and energy: electromagnetic fields, active and passive networks, materials and devices of physical electronics, computers and computation, control systems, energy conversion, information and communications systems, and electro-optics. Well-developed tools for analysis and synthesis characterize their engineering studies and design. Modeling, simulation, and realization of prototypes and systems are effectively applied to the economic solution of today's major electrical engineering problems in civilian, consumer, industrial, commercial and military endeavors.

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

Facilities

The facilities of the Electrical Engineering Department include adequate instructional laboratories in East Engineering Building and the following laboratories primarily devoted to research: Cooley electronics, digital computer engineering, electromagnetic materials, electron physics, information systems, plasma engineering, radiation, radio astronomy, space physics research and systems engineering. The facilities of the Communication Sciences Laboratory are available to students in electrical engineering for instruction and 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 proficiences to be demonstrated (see page 42)
B. Professional and advanced subjects and electives

	Hours
Eng. Graphics 104, Descriptive Geometry	2
Chem.-Met. Eng. 250, Principles of Engineering Materials	3
Math. 273, Elementary Computer Techniques	2
Math. 450, Advanced Mathematics for Engineers *or* Math 404, Differential Equations	4 or 3
English, Groups II and III	4
Econ. 401, Modern Economic Society	4
Acctg. 271, Accounting or nontechnical elective	3
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

	Hours
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, Principles of Physical Electronics or Elec. Eng. 383, Physical Electronics I	3
Elec. Eng. 381, Physical Electronics Laboratory	1
Elec. Eng. 420, Electromagnetic Field Theory II	3
Elec. Eng. 444, Energy Conversion and Control II	4
Elec. Eng. 470, Electrical Design	4
Humanities and Social Sciences	6
Electives*	10 or 11
Total hours in Group B	95

Representative Schedule (See page 45).
For studies of the first year, see page 25.

Third Term	Hours
Math. 215	4
Math. 273	2
Physics 146	5
Elec. Eng. 210	4
Humanities and Social Science	3
	18

Fourth Term	Hours
Math. 315	2
Math. 316	2
Elec. Eng. 220	3
Chem.-Met. Eng. 250	3
English, Group II	2
Eng. Graphics 104	2
Humanities and Social Science	3
	17

Half Term	
Elec. Eng. 310	4
Mech. Eng. 331	4
	8

Fifth Term	
Elec. Eng. 360	3
Elec. Eng. 380 or Elec. Eng. 383	3
Elec. Eng. 381	1
Eng. Mech. 310	4
Math 450 or Math 404	4 or 3
Econ. 401	4
	19 or 18

Sixth Term	
Elec. Eng. 301	2
Elec. Eng. 330	4
Elec. Eng. 343	3
Eng. Mech. 343	3
Mech. Eng. 252	2
Acctg. 271 or Humanities and Social Science	3
	17

Seventh Term	
Elec. Eng. 444	4
Eng. Mech. 324	3
English, Group III	2
Electives	6 or 5
	15 or 14

Eighth Term	
Elec. Eng. 420	3
Elec. Eng. 470	4
Mech. Eng. 343	3
Electives	5
	15

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

Engineering Mechanics

Program Adviser: Professor Hadley Smith, 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 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, thermodynamics, and micromechanics. 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 flexible group of technical electives. In addition, there are twenty hours in the humanities and social sciences.

Graduate work towards 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.

Facilities

The departmental facilities in the West Engineering Building include the solid mechanics, fluid mechanics, and dynamics laboratories. In addition, laboratories for instruction and research in the basic mechanics of fluids are maintained in the Fluids Engineering Laboratories.

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 42)
B. Professional and advanced subjects and electives

Basic Engineering and Sciences — *Hours*

Engineering materials (3 hours), electricity and electronics (6-8 hours), modern physics (3 hours), thermodynamics (3-4 hours) 15-18
(Typical courses are Chem.-Met. Eng. 250 or 350; Elec. Eng. 210 and

	Hours
310, 314, 315 and 442, or 215 and 337; Physics 453 or Nuc. Eng. 411; Mech. Eng. 331 or Chem. 265 or Physics 406)	
Engineering Mechanics	13
(Eng. Mech. 218, 345, 319, and 324 or equivalent)	
Mathematics	
Differential equations, advanced mathematics for engineers, and Fourier series or operational methods	10-11
(Typical courses are Math. 404, 450, and 552 or 448)	
Engineering, Computation, Design, and Experimentation	
Computer techniques, engineering design	3-4
(Typical courses are Math. 273 and Mech. Eng. 343)	
Mechanics laboratory	6
(Eng. Mech. 328, 402 and 403)	
Intermediate Mechanics	
Dynamics and the mechanics of solids and fluids	9
(Eng. Mech. 442, 412 and 422)	
Technical Electives	
Engineering, science, and mathematics	14-19
Humanities and the Social Sciences	20
English (Groups II and III) (4 hours)	
Electives (16 hours)	
(Economics, foreign languages, literature, history, political science, etc.)	
Total hours in Group B	95

It is required that the technical electives in engineering, science and mathematics include at least two sequences, each consisting of at least three courses or two courses beyond a required course. At least one sequence should be correlated with the required course in design. The electives in the humanities and social sciences must include a sequence of at least two courses, one of which goes beyond the introductory level.

The probable area of future employment or graduate study should be a factor in selecting the elective courses. The student should consult the program adviser for guidance and approval in choosing electives and planning his program.

Examples of sequences which build on the intermediate mechanics courses Eng. Mech. 412, 422, 442 are as follows:

Dynamics
Aero. Eng. 441, Mechanics of Flight and
Info. and Cont. Eng. 570, Principles of Automatic Control I
or
Info. and Cont. Eng. 570, Principles of Automatic Control I

Mechanics of Vibrations
Eng. Mech. 541, Intermediate Vibration Theory and
Eng. Mech. 545, Vibrations of Continuous Media
or
Eng. Mech. 548, Lattice Dynamics

Mechanics of Solids and Structures
Eng. Mech. 411, Structural Mechanics and
Eng. Mech. 514, Theory of Elasticity

Mechanics of Fluids and Hydraulics
Eng. Mech. 523, Mechanics of Viscous Fluids I and
Eng. Mech. 529, Advanced Laboratory in Fluid Mechanics
or
Mech. Eng. 421, Dynamics and Thermodynamics of Compressible Flow
or
Civ. Eng. 421, Hydraulics
or
Aero. Eng. 520, Intermediate Aerodynamics

Foundations of Continuum Mechanics
Eng. Mech. 555, Statistical Foundations of Mechanics and
Eng. Mech. 548, Lattice Dynamics
or
Eng. Mech. 507, Theory of a Continuous Medium I

Representative Schedule (See page 45)

First Term	*Hours*
Math. 115	4
Chem. 104	4
Eng. Graphics 101	3
English 111	3
English 121	1
	15

Second Term	*Hours*
Math. 116	4
Chem. 106	4
Physics 145	5
English 112	2
	15

Third Term	
Math. 215	4
Eng. Mech. 218	3
Physics 146	5
English, Group II	2
Humanities and Social Sciences	3
	17

Fourth Term	
Math. 315 & 316	4
Chem. 265	4
Eng. Mech. 345	3
Chem.-Met. Eng. 250	3
Humanities and Social Sciences	3
	17

Half Term	
Math. 404	3
Technical elective	3
	6

Fifth Term	
Math. 450	4
Math. 273	2
Eng. Mech. 319	4
Eng. Mech. 324	3
Elec. Eng. 215	4
	17

Sixth Term	
Math. 552	3
Eng. Mech. 328	1
Eng. Mech. 422	3
Elec. Eng. 337	4
Technical elective	3
Econ. 401	4
	18

Seventh Term	
Eng. Mech. 442	3
Eng. Mech. 412	3
Eng. Mech. 402	2
Technical elective	4
English, Group III	2
Humanities and Social Sciences	3
	17

Eighth Term	
Physics 453	3
Eng. Mech. 403	2
Technical elective	2-3
Technical elective	4-3
Design elective	3
Humanities and Social Sciences	2
	16

Industrial Engineering

Program Adviser: Professor Gage, 239 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 operating 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 flow analysis, scheduling and inventory systems, data processing systems, operations research, engineering economics, experimental design, resource allocation, and organizational and managerial control practices.

Facilities

As an aid to the student's education, the department has well-equipped laboratories in the following areas: human performance, industrial systems, plant flow analysis, and computation (calculators and small computers).

In addition to the facilities on campus, the department has excellent relationships with various local firms around the Ann Arbor-Detroit area so that the student is exposed to actual operating industrial, service, and other business systems.

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 42)
B. Professional and advanced subjects and electives

	Hours
English, Groups II and III	4
Econ. 401	4
Eng. Mech. 210 or 310	4
Chem.-Met. Eng. 250, Principles of Engineering Materials	3
Elec. Eng. 310 or 314 and 315	4
Mech. Eng. 251, Control of Mechanical Properties of Solids	3
Mech. Eng. 333 or 335, Thermodynamics	3
Mech. Eng. 381, Manufacturing Processes	4
Ind. Eng. 371, Stochastic Industrial Processes	3
Ind. Eng. 375, Engineering Linear Programming	2
Ind. Eng. 400, Industrial Management	3
Ind. Eng. 431, Administrative Procedures	3
Ind. Eng. 441, Production and Inventory Control I	3
Ind. Eng. 447, Plant Layout and Materials Handling	3
Ind. Eng. 451, Engineering Economy I	3

	Hours
Ind. Eng. 463, Work Methods and Measurements I	4
Ind. Eng. 473, Data Processing	3
Accounting 271	3
Math. 273, Elementary Computer Techniques	2
Math. 465, 466, Introduction to Statistics I, II	6
*Humanities and Social Sciences	8
*Non-engineering electives	5
*Engineering sequence	15
Total hours in Group B	95

Representative Schedule (See page 45)

For studies of the first year, see page 25.

Third Term	*Hours*	*Fourth Term*	*Hours*
Math. 215	4	Math. 216	4
Acctg. 271	3	Math. 465	3
Math. 273	2	Chem.-Met. Eng. 250	3
Physics 146	5	Ind. Eng. 400	3
Elective	2	Elective	2
	16		15
Fifth Term		*Sixth Term*	
Ind. Eng. 375	2	Ind. Eng. 371	3
Math. 466	3	Ind. Eng. 451	3
Eng. Mech. 310 or 210	4	English, Group II	2
Ind. Eng. 473	3	Mech. Eng. 251	3
Econ. 401	4	Elective	4
	16		15
Seventh Term		*Eighth Term*	
Elec. Eng. 314 and 315 or 310	4	Mech. Eng. 333 or 335	3
Mech. Eng. 381	4	Ind. Eng. 447	3
Ind. Eng. 441	3	Elective	10
Ind. Eng. 463	4		16
English, Group III	2		
	17		
Ninth Term			
Ind. Eng. 431	3		
Electives	10		
	13		

Materials Engineering and Metallurgical Engineering

Program Adviser: Professor W. C. Bigelow, 4213 East Engineering

Materials and metallurgical engineers are concerned with the development and use of the metallic, ceramic, and polymeric materials that are utilized in engineering applications in all fields of science and technology. Historically, such engineering materials have been of tremendous impor-

* All electives must receive the advance approval of the program adviser; a maximum of six hours of advanced air, military, or naval science (300 and 400 series) may be used as engineering electives.

tance in the development of civilization as evidenced by the fact that major periods of history, such as the Stone Age, the Bronze Age, and the Iron Age, have been named on the basis of the most advanced material available at the time for the construction of tools and weapons. Prehistoric man's ability to achieve superiority over hostile animals and unfavorable climatic conditions was unquestionably due to his unique ability to use sticks, stones, hides and other simple, readily-available materials to construct tools, weapons, clothes, and shelters.

Likewise, modern man's ability to sustain the rapid advance of his technologically-oriented society is becoming increasingly dependent on his ability to develop new types of materials and to devise new ways to utilize existing materials. For example: the production of the automobile under highly competitive conditions has not only led to the refinement of mass production techniques but also to many advances in understanding and controlling the properties of steel; the development of transistors and related solid-state electronic devices, which have almost totally replaced electron tubes and which have revolutionized the electronics industry, required the development of dozens of new semiconducting materials and a host of new manufacturing processes; the development of rocket and jet engines for aerospace applications required a new class of alloys having high strengths and resistance to oxidation at the high service temperatures encountered in these devices; and, as evidenced by everyday experience, plastics of various kinds are replacing metal, glass, wood, paper, leather, and natural fibers in the manufacture of containers, shoes, clothing, paints, tools, appliances, toys, and a variety of other common commodities.

Thus, selection, development, and utilization of engineering materials have become critical factors in many modern engineering research, development and production endeavors, and this has given rise to a growing demand for scientists and engineers who have the knowledge and training to undertake these challenging tasks at the frontiers of science and technology.

The programs in Materials Engineering and Metallurgical Engineering should be particularly attractive to students who enjoyed their introductory courses in chemistry and physics, because information from these basic sciences is used throughout both programs to explore the chemical bonding, atomic and molecular arrangements, crystal structures, phase distributions, and microstructures of the various types of materials and to understand how these structural characteristics determine their mechanical and physical properties.

The beginning courses are the same for both programs and, in addition to exploring the fundamental principles described above, provide laboratory experience with basic processing operations such as melting, casting, sintering, rolling, and heat treating, and with the basic techniques used for studying structures and measuring properties. At the upper class level the Materials Engineering program allocates roughly equal time for general studies of the selection, control, and utilization of metals, ceramics, and polymers, while the courses in the Metallurgical Engineering program cover in detail all phases of metallurgy including extractive methods, mechanical processing, heat treating to control structure and properties, and the selection and utilization of metals.

Laboratory work at this level provides opportunities for gaining experience with modern research equipment such as X-ray radiographic and diffraction units, electron microscopes, and X-ray microprobes and fluorescence analyzers, for working on research projects, and for designing industrial processes and equipment.

To round out their technical training, metallurgical and materials engineers require a sound basis in thermodynamics, mechanics, electrical circuits, and other engineering science subjects plus advanced courses in mathematics, physics, and chemistry. In addition, they are urged to elect significant courses in the humanities and social sciences to provide the best possible basis for future enjoyment of, and participation in, the cultural, political, economic, and social activities of their communities.

Facilities

The facilities for the programs in materials and metallurgical engineering are housed in the East Engineering Building. These include: laboratories equipped for basic studies of the structures and properties of metals, ceramics, and polymers; special purpose laboratories for studies of cast metals, electrochemical and corrosion processes, high temperature alloys, crystal plasticity, and liquid metals systems; and instrument laboratories containing radiographic equipment, X-ray diffraction and fluorescence units, electron microscopes, an electron microprobe analyzer, mass spectrometers, an optical spectrograph, gas chromatographic equipment, infrared and ultraviolet spectrometers, and precision mechanical testing equipment.

Requirements

Candidates for the degree B.S.E.(Mat.E.)—Bachelor of Science in Engineering (Materials Engineering) or B.S.E.(Met.E.)—Bachelor of Science in Engineering (Metallurgical Engineering)—are required to complete the following program with the election of the appropriate option.

A. Subjects to be elected, or equivalent proficiencies to be demonstrated (see page 42)

B. Professional and advanced subjects and electives:

Hours

1. Humanities and Social Sciences 22*
   (Must meet college distribution requirements and include one course in economics).

2. Advanced Mathematics and Science 15*
   These courses must, in general, have Group A courses in Mathematics and science as prerequisites, and must include a course in electronic computers and a course in physical chemistry. Materials engineers must also include a course in organic chemistry.

3. Engineering Science and Design 17*
   These courses must include one course in mechanics, e.g. Eng. Mech. 310; one course in electircal circuits, e.g. Elec. Eng. 314 and

* The number of credits for any of these four groups may be increased by as much as 3 credits with a corresponding reduction in credit for any group of higher number.

	Hours
315; and one course in materials, e.g. Chem-Met. Eng. 250. Materials engineers must also include a design course such as Elec. Eng. 470, Mech. Eng. 460, or Chem.-Met. Eng. 480, 481, or 489.	
4. Professional Engineering Subjects	36*
Chem.-Met. Eng. 200, Introduction to Engineering Calculations 3	
Chem.-Met. Eng. 230, Thermodynamics I (without lab) 4	
Chem.-Met. Eng. 351, Structure and Properties of Materials 3	
Chem.-Met. Eng. 371, Physical Metallurgy I 3	
Degree Options† 23	
5. Electives	5
	95

* The number of credits for any of these four groups may be increased by as much as 3 credits with a corresponding reduction in credit for any group of higher number.

† Option for B.S.E. (Mat. E.)		† Option for B.S.E. (Met. E.)	
Chem.-Met.Eng. 450	4	Chem.-Met.Eng. 341	3
Chem.-Met.Eng. 451	4	Chem.-Met.Eng. 489	4
Chem.-Met.Eng. 341, 455, 472 (2 of 3 courses)	6	Chem.-Met.Eng. 455, 472, 475, 477 (3 of 4 courses)	9
Selections from 400 and 500 Chem.-Met.Eng. courses	9	Selections from 400 and 500 Chem.-Met. Eng. courses	7

Representative Schedule (See page 45)

First Term	*Hours*	*Second Term*	*Hours*
Math. 115	4	Math. 116	4
Chem. 107	5	Physics 145	5
English 111	3	English 112, 121	3
Fresh. Engineering	3	Eng. Sci. or Des. (3)*	3
	15		15
Third Term		*Fourth Term*	
Math. 215	4	Math. 216	4
Math. 273 (2)*	2	Chem. 265 (2)*	4
Physics 146	5	Chem.-Met. Eng. 200 (4)*	3
Chem.-Met. Eng. 250 (3)*	3	Humanities & Social Science (1)*	4
Humanities & Social Science (1)*	3	Elective (5)*	2
	17		17
Fifth Term		*Sixth Term*	
Chem.-Met. Eng. 351 (4)*	3	Chem.-Met. Eng. 371 (4)*	3
Chem. 266 (2)*	4	Adv. Sci. or Math. (2)*	5
Chem.-Met. Eng. 230 (4)*	4	Eng. Sci. or Des. (3)*	4
Humanities & Social Science (1)*	4	Degree option (4)*	3
Elective (5)*	3	Humanities & Social Science (1)*	3
	18		18
Seventh Term		*Eighth Term*	
Eng. Sci. and Des. (3)*	4	Eng. Sci. and Des. (3)*	3
Degree option (4)	10	Degree option (4)*	10
Humanities & Social Science (1)*	4	Humanities & Social Science (1)*	4
	18		17

* Numbers in parentheses indicate the subject group under Group B requirements to which the various courses would normally be assigned.

Applied Mathematics

Program Co-advisers: Associate Professor Goldberg, 347A West Engineering, Professor Hadley J. Smith, 312A West Engineering

The applied mathematics program provides the student with an opportunity to extend his knowledge of the common language of the mathematician and the engineer or scientist, and to become proficient in the combination of mathematical and physical reasoning needed for the formulation and solution of technical problems. This program recognizes the ever increasing demand that the changing physical and economic world imposes on both the applied mathematician and on the engineer. It therefore makes available to the student the knowledge with which he can better understand and analyze mathematical models which represent that world.

After a broad training in the fundamentals of mathematics, engineering, and science, the program provides a number of options in several technical areas. Each option contains additional mathematics which is directly related to its technical content.

Requirements

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

A. Subjects to be elected or equivalent proficiencies to be demonstrated (*see page 42*)
B. Professional and advanced subjects and electives

Core Requirement

		Hours
Math. 273, 404 or 286, 417, 425, 451*		14
Elec. Eng. 215, 320	7	
Eng. Mech. 218, 345	6	
Mech. Eng. 331 or Chem. 265 or Chem. 194	4	17
		31

Technical Option

Mathematics	10-15	
Engineering and Science	16-22	27-32

Humanities and Social Sciences

Humanities (English, Art, Music, Phil., etc., including at least 4 hours of literature)	4-14	
Social Sciences (Hist., Pol. Sci., Psych., Econ., etc.)	6-14	
Foreign Language	0-16	26
Free Electives		6-11
Total hours in Group B		95

The requirement for a technical option must be satisfied by electing a group of courses approved in advance by adviser. Electives are required to be approved by the adviser as possessing an adequate degree of coherence. For this purpose, some sequences which total at least 6 credit-hours each will usually be required.

* Students who fulfill the prerequisite for Math. 451 by means of Math. 350, can request substitution of two credit hours of Math. 350 for Math. 315 of Group A and apply one hour to the technical option or the electives of Group B. Students who elect Math. 450 can request substitution of Math. 450 and Math. 594 for Math. 451 and part of the option or the electives.

The student normally should select a technical option during or prior to the fourth term to insure that his adviser can assist him in arranging an efficient schedule. However, a choice or change of option during the fifth term will not usually extend the time to complete the degree requirements. In any event, it is advisable to elect Eng. Mech. 218 no later than the third term and to elect Math. 273, Elec. Eng. 215, Eng. Mech. 345, and a course in thermodynamics by the fourth term. The latter course will normally be Mech. Eng. 331. However, students who fulfill the Group A requirements by means of the Unified Science Program, or who have definitely selected an option requiring Sci. Eng. 330 or Chem.-Met. Eng. 350, usually should elect Chem. 194 or 265, respectively.

Typical technical options are as follows:

Aeronautics		*Hours*
Math. 440, 473, 552, 555		11
Eng. Mech. 319	4	
Aero. Eng. 320, 330	7	
and two of 314, 414, 420, 441, 520	8	19
		30

Electrics		
Math. 440, 473, 552, 555		11
Chem.-Met. Eng. 250, Eng. Mech. 324	7	
and one of the following sequences		
Electronics and Communications:		
Elec. Eng. 330, 380, 430	12	
Electromagnetic Fields and Properties:		
Elec. Eng. 380, 420, 480	9	
Circuits and Networks:		
Elec. Eng. 310, 410, 415, 515	12	16-19
		27-30

Mechanics		
Math. 440, 473, 552, 555		11
Two approved cognates in science or engineering, such as two of Chem. 266, Chem.-Met. Eng. 350 or 250, Elec. Eng. 420, Physics 307, 453	6-7	
and one of the following sequences		
Dynamics:		
Eng. Mech. 319 or 326, 403, 442 and one of 412, 422, 500-level	11-12	
Mechanics of Solids:		
Eng. Mech. 319, 403, 412 and one of 422, 442, 500-level	11-12	
Mechanics of Fluids:		
Eng. Mech. 326, 403, 422 and one of 412, 442, 500-level	11-12	17-19
		28-30

Numerical Analysis and Computer Science		
Math. 468, 473, 555, 571 or 572		12
Eng. Mech. 326 or 442	3-4	
Phil. 233 or 296 or 414	3	
Elec. Eng. 465, 466 and 467 or 560 or 565 or Math. 573	9	
Ind. Eng. 575 or Math. 518	3	18-19
		30-31

Operations Research		*Hours*
Math. 468, 518, 554		10
Sci. Eng. 330, Sci. Eng. 340 or Eng. Mech. 326	8	
Elec. Eng. 420, 442	7	
Ind. Eng. 371, Ind. Eng. 441	6	21
		31

Physics		
Math. 440, 552, 555, and 468 or 473 or Physics 451		11
Elec. Eng. 380, 381, 420, Eng. Mech. 326	11	
Three of Physics 307, 402, 409, 453, 457	8-9	19-20
		30-31

Rate Processes		
Math. 440, 448, 473, and 552 or, 571 or 572		12
Chem.-Met. Eng. 250	3	
and one of the following sequences		
Chemical Engineering Sequence:		
Sci. Eng. 330, Chem.-Met. Eng. 341, 342, and two of 343, 400, 446, 500, 501	17	
Mechanical Engineering Sequence:		
Eng. Mech. 326, Mech. Eng. 324, 336, 471	16	19-20
		31-32

Systems and Control		
Math. 473, 571 or 572, 594		9
Chem.-Met. Eng. 250, Eng. Mech. 326, Elec. Eng. 301	9	
and one of the following sequences		
Electrical Engineering Sequence:		
Math. 552, 555, Elec Eng. 343 and 445 or 549	12	
Information and Control Engineering Sequence:		
Math. 448, Info. and Cont. Eng. 510, 570, 571	11	
Industrial Engineering Sequence:		
Math. 554, Elec. Eng. 343, Ind. Eng. 472 and 441 or 541	13	20-22
		29-31

General Option		
Math. 473, 552, 555, and two of 468, 518, 571 or 572, 590		15
Sixteen hours of approved engineering and science, such as Elec. Eng. 420, Eng. Mech. 319 or 326, Eng. Mech. 403, Physics 307 or 453, Sci. Eng. 330		16
		31

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 the national 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, and 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 non-technical 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.

Facilities

The laboratories of the Department of Mechanical Engineering, in the Fluids Engineering and Automotive Laboratories on the North Campus and in the East Engineering Building on the Central Campus, provide facilities for both instruction and research.

The Fluids Engineering Building contains the thermodynamics, heat transfer, and fluid flow laboratories, a drop-tower for zero-g heat transfer studies and a large centrifuge for high-g investigations, cryostats for low temperature research in thermodynamic properties and phase behavior, a shock tube facility for high temperature studies, and equipment for research in fluid amplifiers, chemical kinetics, gas dynamics, and direct energy conversion.

The Automotive Laboratory Building houses the mechanical analysis laboratory with a wide variety of electromechanical instrumentation and the analog computer in the experimental analysis of dynamics of mechanical systems; the combustion laboratory with a gas chromatograph and an infrared spectrometer; the friction, lubrication, and wear laboratory; and the facilities for automotive engineering, which include a number of well-instrumented test cells for reciprocating engines, a test cell for a small aircraft gas turbine, an automotive gas turbine installation, as well as a number of single cylinder engines.

The machine tool laboratory is equipped for research in such areas as ultrasonics, high-speed machining, numerical control and vibrations, and instruction in the fundamentals of manufacturing processes. The materials laboratory provides facilities for investigations in such areas as acoustic emission in metals, brittle fracture, heat treating, plasticity, and surface phenomena. A well-equipped welding laboratory is also a part of the East Engineering complex.

Requirements

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

A. Subjects to be elected or equivalent proficiencies to be demonstrated (see page 42)

B. Professional and advanced subjects and electives

	Hours
Electives in humanities, arts, and social sciences	10
English, Groups II and III	4
Econ. 401, Modern Economic Society	4
Chem.-Met. Eng. 250, Principles of Engineering Materials	3
Eng. Graphics 104, Descriptive Geometry	2
Eng. Mech. 208, Statics	3
Eng. Mech. 210, Mechanics of Material	4
Eng. Mech. 324, Fluid Mechanics	3
Eng. Mech. 343, Dynamics	3
Math. 273, Elementary Computer Techniques	2
Mech. Eng. 251, Control of Mechanical Properties of Solids	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 Mechanical Systems	4
Mech. Eng. 362, Mechanical Design I	3
Mech. Eng. 381, Manufacturing Processes	4
Mech. Eng. 460 or 462, Mechanical Design II*a* or II*b*	3
Mech. Eng. 461, Automatic Control	3
Mech. Eng. 471, Heat Transfer I	4
Elec. Eng. 314. Circuit Analysis and Electronics	3
Elec. Eng. 315, Circuit Analysis and Electronics Laboratory	1
Elec. Eng. 442, Analysis of Electromechanical Devices	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 engineering, automatic control, fluid flow, instrumentation, manufacturing, mechanical design, and thermal systems, including heat transfer and stationary or propulsive power plants.

The student is encouraged to formulate his own sequence of elective courses, with the advice, and subject to the approval, of his adviser.

Representative Schedule (See page 45)

First Term	*Hours*	*Second Term*	*Hours*
Math. 115	4	Math. 116	4
Chem. 104	4	Chem. 105	4
Eng. Graphics 101	3	Physics 145	5
English 111	3	English 112	2
English 121	1		
	15		15

* This group of electives should include 3 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, military, or naval science (300 and 400 series) may be used as electives in this group.

Third Term	Hours	*Fourth Term*	Hours
Math. 215	4	Math. 216	4
Physics 146	5	Eng. Mech. 210	4
Eng. Mech. 208	3	Chem.-Met. Eng. 250	3
Eng. Graphics 104	2	Mech. Eng. 335	3
English, Group II	2	Math. 273	2
	16		16

Fifth Term		*Sixth Term*	
Mech. Eng. 251	3	Eng. Mech. 324	3
Mech. Eng. 336	4	Elec. Eng. 314	3
Eng. Mech. 343	3	Elec. Eng. 315	1
Adv. Math.	3	Mech. Eng. 340	4
Humanities	4	Mech. Eng. 381	4
		English, Group III	2
	17*		17*

Seventh Term		*EighthTerm*	
Mech. Eng. 324	4	Mech. Eng. 461	3
Mech. Eng. 362	3	Mech. Eng. 471	4
Elec. Eng. 442	4	Technical Electives	5
Econ. 401	4	Humanities	4
Technical elective	3		
	18*		16*

Half Term	*or*	*Ninth Term*	
Mech. Eng. 460 or 462	3	*Load adjustment *or* extra credits	7
Technical Elective	3	Mech. Eng. 460 or 462	3
Humanities	2	Humanities	2
	8		12

Meteorology and Oceanography

Program Co-advisers: Professor Dingle, 2305 East Engineering, Associate Professor Epstein, 2038 East Engineering

Meteorology and oceanography are the two sciences concerned with the description and explanation of all phenomena in the atmosphere, the oceans, and the boundary between them. The two sciences encompass therefore both basic and applied problems. The increased recognition of the importance of the atmosphere and the oceans in a wide range of human activities has created a demand for meteorologists and oceanographers with a broad basic knowledge of the many processes which take place in the water and the air, and an ability to apply this knowledge to specific problems ranging from the bottom of the ocean to the top of the atmosphere. The qualified meteorologist or oceanographer will find employment in the official weather services, in the space sciences, in industry,

* This program can be completed, as shown above, in eight and one-half terms. As an alternative, the student may expand the half term to a full ninth term by transferring credits from other terms with high credit totals or numerous courses, thereby adjusting the credit load per term. Other representative schedules with different distributions may be found with the program adviser.

government, teaching, research, and in private practice. The immediate need is great, and there is every evidence that the need will continue for years to come.

The understanding of processes in the atmosphere and oceans requires knowledge in many areas of the mathematical and physical sciences. Although the fundamental laws are those of classical hydrodynamics and thermodynamics, it is as a rule necessary to modify these laws before applying them to a specific problem of atmospheric or oceanic interest, because the atmosphere and oceans are thermodynamically active systems receiving energy from many physical processes such as short and long wave radiation, condensation, and interaction with the other medium and dissipating energy through frictional processes.

The applied aspects of the two sciences cover a wide range of activities and interests. The applied meteorologist will be called upon to solve meterological problems in connection with air pollution, industrial plant location and processes, the design of structures and the wind loading on them. Many important decisions on transportation, whether by land, water, or air, depend critically on meteorological factors. The applied oceanographer is concerned with water supply and control, water pollution, wave action on structures and beaches, biological and geological processes in the ocean, and many other problems.

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.(Meteor. & Ocean.)—Bachelor of Science (Meteorology and Oceanography); he thus acquires knowledge in depth in one discipline while obtaining good working knowledge in the rest. These options are:

Option 1. Aeronomy is the physics of the upper atmosphere. This field is treated separately because of the special electrical and magnetic properties of the upper layers of the atmosphere.

Option 2. Meteorology is the physics of the lower atmosphere, its dynamics, thermodynamics, radiation, cloud physics and precipitation processes, interaction with the ground and ocean, the general circulation of the atmosphere and physical weather forecasting.

Option 3. Oceanography is the physics of the oceans. In addition to basic disciplines which are rather parallel to those of Option 2, the program emphasizes geological and biological aspects of oceanography.

Facilities

The Department of Meteorology and Oceanography includes laboratories for atmospheric turbulence and scintillation, cloud and precipitation physics, a computer laboratory containing a hybrid analog-digital computer, meteorological instrumentation, oceanography and submarine geology.

Requirements

Candidates for the degree B.S. (Meteor. & Ocean.)—Bachelor of Science

(Meteorology and Oceanography)—are required to complete the following program:

A. Subjects to be elected or equivalent proficiencies to be demonstrated (see page 42)

B. Professional and advanced subjects and electives

	Hours
English, Groups II and III	4
Chem. 265, Physical Chemistry	4
Eng. Mech. 218 or 208, Statics	3
Eng. Mech. 345 or 343, Dynamics	3
Eng. Mech. 326 or 324, Fluid Mechanics	4 or 3
Elec. Eng. 314, Circuit Analysis and Electronics	3
Elec. Eng. 315, Circuit Analysis and Electronics Laboratory	1
M.&O. 304, Introduction to Atmospheric and Oceanic Sciences I	3
M.&O. 305, Introduction to Atmospheric and Oceanic Sciences II	3
M.&O. 306, Laboratory in Geophysical Data I	2
M.&O. 307, Laboratory in Geophysical Data II	1
M.&O. 331, Atmospheric Heat and Thermodynamics	3
Options 1, 2, or 3	61 or 62
Total hours in Group B	95

One of the following options should be selected by the student to complete his degree work:

1. Aeronomy

Math. 450, Advanced Mathematics for Engineers I	4
Aero. Eng. 425, Principles of Aerodynamics	3
Physics 402, Light	3
Physics 405, Intermediate Electricity and Magnetism	3
Physics 406, Heat and Thermodynamics	3
Physics 425, Introduction to Infrared Spectra	2
Physics 453, Atomic and Nuclear Physics I	3
M.&O. 332, Radiative Processes in the Atmosphere	3
M.&O. 351, Geophysical Fluid Dynamics	3
M.&O. 464, Aeronomy I	3
M.&O. 465, Aeronomy II	3
Electives in mathematics, engineering science, physical science, biological science*	10 or 11
Electives in the humanities and social sciences	18
	61 or 62

2. Meteorology

Math. 450, Advanced Mathematics for Engineers I	4
Sci. Eng. 330, Thermodynamics	4
M.&O. 312, Physical Climatology	3
M.&O. 332, Radiative Processes in the Atmosphere	3
M.&O. 351, Geophysical Fluid Dynamics	3
M.&O. 411, Cloud and Precipitation Processes	3
M.&O. 451, Atmospheric Dynamics I	4
M.&O. 454, Laboratory in Weather Analysis	3
M.&O. 462, Meteorological Instrumentation	3
Electives in mathematics, engineering science, physical science, biological science*	13 or 14
Electives in the humanities and social sciences	18
	61 or 62

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

3. Oceanography

	Hours
Sci. Eng. 330, Thermodynamics	4
Geol. 111 or 218	4 or 3
Zool. 101	4
Zool. 443, Limnology and Oceanography	3
M.&O. 312, Physical Climatology	3
Sequence in marine geology, marine biology, or dynamic oceanography	11 to 14
Electives in mathematics, engineering science, physical science, biological science*	11 to 7
Foreign language	0 to 8
Electives in the humanities and social sciences	22 to 14
	61 or 62

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.

Representative Schedule (See page 45)

For studies of the first year, see page 25

Third Term	*Hours*
Math. 215	4
Physics 146	5
Eng. Mech. 218 or 208	3
M.&O. 304	3
M.&O. 306	2
	17

Fourth Term	*Hours*
Math. 216	4
Eng. Mech. 345 or 343	3
M.&O. 305	3
M.&O. 307	1
Chem. 265	4
English, Group II	2
	17

Fifth Term	*Option 1*	*2*	*3*
Eng. Mech. 324	3	3	3
Elec. Eng. 314	3	3	3
Elec. Eng. 315	1	1	1
Geol. 111	—	—	4
Physics 402	3	—	—
M.&O. 331	3	3	3
Electives	4	3	—
Sci. Eng. 330	—	4	4
	17	17	18

Sixth Term	*Option 1*	*2*	*3*
Math. 450	4	4	—
Physics 405	3	—	—
Physics 406	3	—	—
English, Group III	2	2	2
M.&O. 332	3	3	3
M.&O. 312	—	3	3
Zool. 101	—	—	4
Electives	2	5	5
	17	17	17

Summer Term: Electives 6 hours

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

Seventh Term	*Hours Option 1*	*2*	*3*
M.&O. 411	—	3	—
M.&O. 351	4	4	4
M.&O. 462	—	3	—
M.&O. 464	3	—	—
Physics 425	2	—	—
Zool. 443	—	—	3
Aero. Eng. 425	3	—	—
Language	—	—	4
Electives	5	7	6
	17	17	17

Eighth Term	*Hours Option 1*	*2*	*3*
M.&O. 451	—	4	—
M.&O. 454	—	3	—
M.&O. 465	3	—	—
M.&O. 442	—	—	4
Physics 453	3	—	—
Language	—	—	4
Electives	11	10	8
	17	17	16

Naval Architecture and Marine Engineering

Program Advisers: Option 1: Professor Yagle, 448E West Engineering; Option 2: Assistant Professor Woodward, 330A West Engineering; Option 3: Professor Yagle, 448E West Engineering

The program of study in naval architecture and marine engineering covers all aspects of ship hull design and ship power plants. For example, 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 term and receive an additional 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 aerospace 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 41).

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.

Facilities

A large ship-model towing tank complete with shops and instrumentation is operated by the department for teaching and student and faculty research. A new wave tank has just been completed at North Campus.

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 program:

A. Subjects to be elected or equivalent proficiencies to be demonstrated (see page 42)

B. Professional and advanced subjects and electives

	Hours
Chem.-Met. Eng. 250, Principles of Engineering Materials	3
English, Groups II and III	4
Math. 273, Elementary Computer Techniques	2
Mathematics (additional work beyond Math. 216)	3
Econ. 401, Modern Economic Society	4
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. 314, Circuit Analysis and Electronics	3
Elec. Eng. 315, Circuit Analysis and Electronics Laboratory	1
Nav. Arch. 200, Introduction to Practice	3
Nav. Arch. 201, Form Calculations and Static Stability I	3
Nav. Arch. 310, Structural Design I	3
Nav. Arch. 400, Maritime Engineering Management	2
Nav. Arch. 420, Resistance, Propulsion, and Propellers	4
Electives in humanities and social sciences	9
Free elective	2
Option 1, 2, or 3	32
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: Professor Yagle

Mech. Eng. 337, Mechanical Engineering Laboratory	2
Eng. Mech. 411, Structural Mechanics	3
Nav. Arch. 300, Form Calculations and Static Stability II	2
Nav. Arch. 330, Marine Machinery I	3
Nav. Arch. 331, Marine Machinery II	3

	Hours
Nav. Arch. 410, Stress Analysis of Ship Structures	2
Nav. Arch. 440, Ship Dynamics	3
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
Technical electives	4
	32

2. **Marine Engineering.** Adviser: Assistant Professor Woodward

Mech. Eng. 336, Thermodynamics II	4
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	3
Nav. Arch. 431, Design of Marine Power Plants II	3
Nav. Arch. 446, Theory of Ship Vibrations I	3
Nav. Arch. 473, Design of Marine Power Plants III	3
Technical elective	2
	32

3. **Maritime Engineering Science.** Adviser: Professor Yagle

Nav. Arch. 330, Marine Machinery I	3
Nav. Arch. 331, Marine Machinery II	3
Eng. Mech. 403, Experimental Mechanics	2
	8

Either of the following two sequences:

Eng. Mech. 412, Intermediate Mechanics of Material	3
Eng. Mech. 442, Intermediate Dynamics	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 four hours must be in mathematics and naval architecture, respectively.

Ind. Eng. 472, Operations Research	3
Info. and Cont. Eng. 510, Applications of the Electronic Differential Analyzer I	3
Info. and Cont. Eng. 570, Principles of Automatic Control	3
Info. and Cont. Eng. 571, Automatic Control Laboratory	1
Eng. Mech. 422, Intermediate Mechanics of Fluids	3
Math. 447, Modern Operational Mathematics	2
Math. 448, Operational Methods for Systems Analysis	4
Math. 473, Introduction to Digital Computers	3
Math. 552, Fourier Series and Applications	3
Math. 554, Advanced Mathematics for Engineers II	4
Math. 555, Introduction to Functions of a Complex Variable with Applications	3
Math. 557, Intermediate Course in Differential Equations	3
Physics 305, Modern Physics	2

	Hours
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. 440, Ship Dynamics	3
Nav. Arch. 470, Ship Design I	3
Nav. Arch. 572, Economics of Ship Design and Operation	2
Nav. Arch. 630, Nuclear Ship Propulsion	3
Nuc. Eng. 400, Elements of Nuclear Engineering	3

Representative Schedule (See page 45)

First Term	*Hours*
Math. 115	4
Chem. 107	5
Eng. Graphics 101	3
English 111	3
English 121	1
	16

Second Term	*Hours*
Math. 116	4
Physics 145	5
Free Elective	2
English 112	2
Humanities	4
	17

Third Term	
Math. 215	4
Physics 146	5
Eng. Mech. 208	3
Nav. Arch. 200	3
English, Group II	2
	17

Fourth Term	
Math. 216	4
Eng. Mech. 210	4
Eng. Mech. 212	1
Nav. Arch. 201	3
Chem-Met. Eng. 250	3
Math. 273	2
	17

Fifth Term	
Eng. Mech. 324	3
Eng. Mech. 343	3
Nav. Arch. 310	3
Math.	3
Mech. Eng. 335	3
Humanities	2
	17

Sixth Term	*Option 1*	*2*	*3*
Nav. Arch. 300	2	—	—
Nav. Arch. 330	3	—	3
Nav. Arch. 400	2	2	—
Nav. Arch. 420	4	—	4
Nav. Arch. 430	—	3	—
Mech. Eng. 336	—	4	—
Mech. Eng. 337	2	—	—
Mech. Eng. 471	—	4	—
Elec. Eng. 314	3	3	3
Elec. Eng. 315	1	1	1
Technical Elective	—	—	6
	17	17	17

Seventh Term	*Option 1*	*2*	*3*
Nav. Arch. 331	3	—	3
Nav. Arch. 400	—	—	2
Nav. Arch. 420	—	4	—
Nav. Arch. 431	—	3	—
Nav. Arch. 440	3	—	—
Nav. Arch. 470	3	—	—
Eng. Mech. 411	3	3	—
English, Group III	2	2	2
Econ. 401	4	4	4
Technical Electives	—	2	6
	18	18	17

Eighth Term	*Option 1*	*2*	*3*
Nav. Arch. 410	2	—	—
Nav. Arch. 446	3	3	—
Nav. Arch. 471	2	—	—
Nav. Arch. 472	2	—	—
Nav. Arch. 473	—	3	—
Eng. Mech. 403	—	—	2
Nuc. Eng. 400	—	3	—
Elec. Eng. 442	—	4	—
Humanities	3	3	3
Technical Electives	4	—	12
	16	16	17

Nuclear Engineering

Program Adviser: Professor Dietrich H. Vincent

Nuclear Engineering applies the basic sciences to the design, operation, and use of nuclear energy sources. The primary sources are fission and fusion reactors. A study of such sources requires investigation of a broad spectrum of problems in the general field of interaction of radiation with matter in all states. Transport theory, kinetic theory, and studies, both theoretical and experimental, of nuclear, atomic, and electromagnetic interactions receive primary emphasis. The Department of Nuclear Engineering has teaching and research programs in:

a) Reactor theory and reactor design applications
b) Plasma physics and thermonuclear theory
c) Radiation effects (including radiation detection) and neutron physics of materials
d) Fluid flow and heat transport phenomena

The challenge to the nuclear engineer is twofold: first, his knowledge of the applied sciences must be broad; and second, he must apply his knowledge to problems which are at the forefront of basic science. Since the applied nuclear energy effort in the world is expanding at a high rate, the need for nuclear engineers is great.

Facilities

Special facilities available to nuclear engineering students includes the following:

2 megawatt swimming pool research reactor
Subcritical assembly and Sigma pile
Analog computer
Single crystal neutron spectrometer and single rotor chopper
Triple axis crystal neutron spectrometer
Four rotor phased thermal neutron chopper
150 kv Cockroft-Walton accelerator which can be used as a pulsed neutron source
10,000 curie Cobalt-60 gamma source
Radiation measuring equipment, including several multichannel analyzers
Radiation solid state laboratory
Electron spin resonance laboratory
Plasma research laboratory
Fluid flow and heat transfer research equipment, including high speed photographic and lighting equipment
Hot laboratories and two hot caves with master-slave manipulators

Requirements

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

A. Subjects to be elected or equivalent proficiencies to be demonstrated *(see page 42)*

B. Professional and advanced subjects and electives

	Hours
Chem.-Met. Eng. 250, Principles of Engineering Materials	3
Econ. 401, Modern Economic Society	4
A course in electronics, such as Elec. Eng. 337 or Physics 455	4
Eng. Mech. 208 or 218, Statics	3
Eng. Mech. 210, Mechanics of Material, or 319, Mechanics of Solids I	4
Eng. Mech. 324 or 326, Fluid Mechanics	3 or 4
Eng. Mech. 343 or 345, Dynamics	3
English, Groups II and III	4
Math. 273, Elementary Computer Techniques	2
Math. 404, Differential Equations	3
Math. 450, Advanced Mathematics for Engineers I	4
Nuc. Eng. 311, Elements of Nuclear Engineering I	3
Nuc. Eng. 312, Elements of Nuclear Engineering II	3
Nuc. Eng. 415, Radiation Detection and Nuclear Measurements I	4
A laboratory course in Nuc. Eng., such as Nuc. Eng. 416 or 425	4
Nuc. Eng. 441, Fission Reactors and Powerplants I	3
Nuc. Eng. 442, Fission Reactors and Powerplants II	3
Nuc. Eng. 471, Controlled Fusion and Plasmas	3
A course in thermodynamics, such as Mech. Eng. 331 or 333, Sci. Eng. 330, or Physics 406	3 or 4
Humanities and Soc. Sci	17
Technical electives (must include three hours in Nuc. Eng.)	15 or 13
Total hours in Group B	95

Representative Schedule (See page 45)

First Term	*Hours*
English 111	3
English 121	1
Math. 115	4
Eng. Graphics 101	3
Chem. 104 or 107	4 or 5
	15 or 16

Second Term	*Hours*
English 112	2
Math. 116	4
Physics 145	5
Chem. 105 or Technical electives	4 to 7
	15 to 18

Third Term	
Math. 215	4
Physics 146	5
English, Group II	2
Eng. Mech. 208	3
Humanities and Soc. Sci.	3
	17

Fourth Term	
Math. 315	2
Math 316	2
Technical Elective	3
Eng. Mech. 210	4
Chem.-Met. Eng. 250	3
Humanities and Soc. Sci.	2
	16

Half Term	
Technical elective	3
Humanities and Soc. Sci.	3
	6

Fifth Term	
Math. 404	3
Math. 273	2
English, Group III	2
Eng. Mech. 343	3
Nuc. Eng. 311	3
Humanities and Soc. Sci	3
	16

Sixth Term	
Math. 450	4
Electronics	4
Eng. Mech. 324	3
Nuc. Eng. 312	3
Technical elective	3
	17

Seventh Term	*Hours*
Nuc. Eng. 441	3
Nuc. Eng. 415	4
Thermodynamics	3-4
Econ. 401	4
Humanities and Soc. Sci.	3
	17 or 18

Eighth Term	*Hours*
Nuc. Eng. 442	3
Nuc. Eng. Lab. Course	4
Nuc. Eng. 471	3
Technical elective	3-4
Humanities and Soc. Sci.	3
	16 or 17

Physics

Program Co-Advisers: Professor Wiedenbeck, 1072 Randall, and Professor Enns, 205 West Engineering

The rapid advance of 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 proficiences to be demonstrated (see page 42)

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	2
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 course in engineering thermodynamics	3
Physics 453, Atomic and Molecular Structure	3
Physics 455, Electron Tubes	4
Group options and electives	34
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 or 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*	6
	34

Science Engineering

Program Adviser: Assistant Professor J. D. Goddard, 4213 East Engineering

Science engineering is an interdepartmental degree program which combines a strong background in mathematics and the physical and engineering sciences with a high degree of flexibility in the choice of the area of engineering specialization. A primary objective of this program is to supplement and reinforce the academic offerings of the several established departments of the College of Engineering. The unique features of this program are its outstanding sequence of basic engineering science courses; the large amount of elective freedom which it allows in the selection of courses in the humanities and social sciences, and in advanced mathematics, chemistry, physics, and engineering subjects; and a basic structure which usually does not require selection of the area of specialization until the fifth or sixth term when students are well acquainted with the possibilities for specialization and with their own interests and aptitudes.

Students electing the Science Engineering Program can acquire a depth of training and experience in engineering principles and practice comparable to that provided by other programs of the College; however, they are not required to take all of the specialized courses normally included in many other programs and are therefore able to devote more time to courses of fundamental scientific nature. As a consequence of its greater elective freedom, the Science Engineering Program offers a greater variety of areas of specialization than any other program in the College. Science engineering students may choose their electives so as to obtain the substantial equivalent of an undergraduate degree in a number of traditional fields of engineering and to prepare for graduate work in these fields. Alternately, they may prepare for future work in law, management, sales, administration, writing and editing, or medicine, or they may specialize in one of the newly developing subject areas which overlap established fields of science and engineering and which may not be available to students in traditional departments. Examples of such subject areas are: nuclear science, instrumentation, communications, radio astronomy, bioengineering, computer science, solid state devices, high temperature gas dynamics, plasma physics, energy conversion, and systems engineering. The Science Engineering Program is particularly well suited for students who transfer to the College of Engineering after

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

one or two years of work at another institution. It is also well suited for students who wish to obtain two degrees in the College of Engineering and for those who wish to participate in the Combined Degree Program leading to bachelor's degrees in both the College of Engineering and the College of Literature, Science, and the Arts.

The Science Engineering Program is administered by an interdepartmental committee whose members work closely with individual Science Engineering students and with counselors in the several departments of the College to select courses which best fulfill each student's academic objectives. Each student, however, is expected to assume the basic initiative and responsibility in developing his own program and in keeping account of his own academic progress. In this connection, it is intended that the elective freedom of the program should be accepted as a challenge to intellectual achievement, and each student is expected to design his program to develop his abilities to the highest possible level.

Requirements

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

A. Subjects to be elected or equivalent proficiencies to be demonstrated (see page 42)

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, fine arts, history of art, music, or 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

Among the Group A subjects, the unified science sequence of accelerated and integrated preparatory courses consisting of Mathematics 185, 186, and 285, Physics 153 and 154, and Chemistry 194 and 195, are strongly recommended for those students who are qualified. The representative schedule on page 86 is expressed in terms of this sequence. It is to be emphasized, however, that the many alternative sequences of preparatory courses with the same terminal level of accomplishment are equally acceptable, but 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

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

adds 1 hour; and the chemistry sequence beginning with Chemistry 103 or 104 adds 4 hours.

For the engineering science courses of the Group B subjects, the special sequences of courses consisting of Engineering Mechanics 218, 319, 326, 345, Electrical Engineering 215, 320, 337, and Science Engineering 330 and 340 are normally recommended. These have been developed by the respective departments, especially for the Science Engineering Program, and are among the most effective, efficient, and challenging courses available in their respective subject areas. Certain equivalent courses, however, 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.

The electives in humanities and social sciences are considered especially important because of the increasing contributions of scientists and engineers to the political, cultural, and philosophical aspects of modern civilization. These electives should therefore be carefully chosen to obtain a significant and meaningful experience in nontechnical subjects. Courses selected from among the offerings of the English Department of the College of Engineering and from among those listed as acceptable for fulfilling distribution requirements in the *Announcement* of the College of Literature, Science, and the Arts are recommended for this purpose. Foreign languages are particularly appropriate for students planning to undertake graduate work for a doctorate degree.

The electives in advanced mathematics, science, and engineering subjects should be chosen with a definite professional objective in mind, and should be such as to provide significant depth of training in engineering principles. The possibilities here are too numerous to list completely; however, several typical groups of electives are given below to illustrate the versatility of the program and to show the depth of professional training expected. Members of the Science Engineering Program Committee will be pleased to assist students in developing elective sequences for specialization in appropriate subject areas other than those shown below.

Typical Elective Sequences

Aerospace: Math. 404 (3), and 450 (4), Aero. Eng. 320 (4) (for fluid mechanics requirements), Aero. Eng. 314 (4), 330 (3), 420 (4), 441 (4), one or more of Aero. Eng. 414 (4), 430 (4), 471 (4), 520 (3), 540 (4), or alternate courses recommended by the aerospace engineering adviser.

Bioengineering: Math. 450 (4), Chem. 225 (3), 226 (3), 227 (2), 346 (4). Biochem. 502 (3), Zool. 106 (4), Chem.-Met. Eng. 341 (3), and 342 (4) (for rate processes requirement) and 448 (3), 484 (3), 485 (3), Civ. Eng. 587 (3), and Elec. Eng. 463 (4), or alternate courses recommended by bioengineering adviser.

Communications Science: Math. 404 (3), or 450 (4), 425 (3), 473 (3), Com. Sci. 400 (3), 410 (3), Elec. Eng. 330 (4), Philos. 101 (4) or 233 (3), 414 (3), and additional courses selected on recommendation of communications science adviser to meet the interests of individual student.

Chemical Engineering: Chem. 225 (3), 226 (3), 227 (2), 265 (4), 266 (4), Chem.-Met. Eng. 200 (3), 230 (5) (for themodynamics requirement), 341 (3) (for rate processes requirement), 342 (4), 343 (4), 460 (3), 480 (3), or 481 (3) or alternate courses recommended by chemical engineering adviser.

Electrical Engineering: Math. 273 (2), 404 (3), 450 (4), Elec. Eng. 310 (4) (not required if an A or high B is obtained in Elec. Eng. 215), 343 (3), 360 (3), 380 (3) (not required if Chem.-Met. Eng. 350 and Phys. 307, 453, or Nuc. Eng. 411 are taken), 410 (3), 420 (3), 444 (4), 470 (4). A number of other sequences for specialization in various areas of electrical engineering can be suggested by the electrical engineering adviser.

Engineering Mechanics: Math. 404 (3), 447 (2), 450 (4), Eng. Mech. 403 (2), 412 (3), 422 (3), 442 (3), and additional courses selected upon recommendation of engineering mechanics adviser.

Heat Transfer and Thermodynamics: Math. 404 (3), 450 (4), 273 (2), Mech. Eng. 531 (3), 471 (4), 571 (3), 672 (3), Chem.-Met. Eng. 430 (3), 480 (3), and additional or alternate courses selected on recommendation of program adviser.

Information and Control Engineering: Math 404 (3), 448 (4), 450 (4), Elec. Eng. 310 (4) (not required with A or B+ in EE 215), Info. and Cont. Eng. 510 (3), 530 (2), 570 (2), 571 (1), and additional courses recommended by information and control engineering adviser.

Materials Engineering: Chem 225 (3), 226 (3), 227 (2), Chem.-Met. Eng. 450 (4), 451 (4), 470 (4), 471 (3), 472 (3), and 480 (3) or 481 (3) or 489 (4) or Mech. Eng. 343 (3) or 362 (3), or alternate courses recommended by materials engineering adviser.

Materials Processing: Chem.-Met. Eng. 250 (3) (for materials requirement), Mech. Eng. 251 (3), 381 (4), 343 (3), and additional courses selected from the following: Chem.-Met. Eng. 477 (3), 479 (3), 535 (3), 576 (3), Mech. Eng. 486 (3), 487 (3), 482 (4), 581 (3), 582 (3), Phys. 307 (3) or 453 (3), or Nuc. Eng. 411 (3), as recommended by materials processing adviser.

Mechanical Engineering: Chem.-Met. Eng. 250 (3) (for materials requirement), Mech. Eng. 251 (3), 324 (4), 336 (4), or 531 (3), 340 (4), 362 (3), 381 (4), 460 (3) or 462 (3), 471 (4) and additional or alternate courses recommended by mechanical engineering adviser.

Metallurgical Engineering: Chem. 225 (3), 266 (4), 346 (4), Math. 273 (2), Chem.-Met. Eng. 470 (4), 471 (3), 472 (3), 477 (3), 489 (4), 490 (3), or alternate courses recommended by metallurgical engineering adviser.

Meteorology and Oceanography: Math. 404 (3), M.&O. 304 (3), 305 (3), 312 (3), 331 (3), 351 (3), 462 (2), and 451 (4), or 452 (4) or alternate courses recommended by meteorology adviser.

Nuclear Engineering: Math. 273 (2), 404 (3), 450 (4), Nuc. Eng. 311 (3), 312 (3), 415 (4), 416 (4), 441 (3), 442 (3), 471 (3), and additional or alternate courses selected upon recommendation of nuclear engineering adviser.

Physics: Math. 404 (3), 450 (4), and 15 credit hours of intermediate physics courses selected from Phys. 401 (3) or 507 (3), 402 (3), 405 (3), or 455 (4) or 456 (3), 406 (3), or 509 (2), 451 (3), 452 (3), 453 (3), 457 (3), upon recommendation of program adviser.

Radio Astronomy: Math. 404 (3), 450 (4), Astron. 421 (3), 422 (3), Elec. Eng. 410 (3), 420 (3), 535 (3), 536 (3), with additional or alternate courses selected from Astron. 535 (3), 536 (3), Elec. Eng. 475 (3), 530 (4), as recommended by radio astronomy adviser.

Solid State Devices: Math. 404 (3), 450 (4), Phys. 453 (3), 463 (3), Chem.-Met. Eng. 551 (3), Elec. Eng. 380 (3) or 383 (3), 381 (1), 420 (3), 483 (3), with additional or alternate courses selected from Chem.-Met. Eng. 550 (3), Elec. Eng. 419 (2), 580 (4), 583 (3), 626 (3), 688 (3), upon recommendation of program adviser.

Structure of Solids: Math. 450 (4), 473 (3), 552 (3), Phys. 453 (3), Mineral. 457 (3), 458 (3), Chem.-Met. Eng. 450 (4), 470 (4), 471 (3), 472 (3), 560 (3), 572 (3), with additional or alternate courses from Chem.-Met. Eng. 535 (3), 550 (3), Mineral. 451 (4), 501 (3), Chem. 767 (2), 769 (2), Phys. 402 (3), as recommended by program adviser.

Representative Schedule (See page 45)
(In terms of accelerated sequences)

First Term	*Hours*	*Second Term*	*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

Third Term		*Fourth Term*	
Math. 285	4	Elective (math.)	4
Chem. 195	4	Physics 154	4
Eng. Mech. 218	3	Eng. Mech. 345	3
Electives (humanities, soc. sci.)	7	Elec. Eng. 215	3
		Electives (humanities, soc. sci.)	4
	18		18

Fifth Term		*Sixth Term*	
Sci. Eng. 330	4	Sci. Eng. 340	4
Elec. Eng. 320	4	Elec. Eng. 337	4
Eng. Mech. 319	4	Eng. Mech. 326	4
Elective (math., chem., physics)	3	Elective (math., chem., physics)	2
Elective (humanities, soc. sci.)	3	Elective (engineering)	4
	18		18

Seventh Term		*Eighth Term*	
Electives (engineering)	6	Electives (engineering)	7
Elective (math., chem., physics)	3		7
Chem.-Met. Eng. 350	3		
Electives	6		
	18		

Reserve Officer Training Corps

Objective: Officer training is available to all University men through the Senior Reserve Officer Training Corps. The purpose of this Corps is to provide a permanent system of training and instruction in essential military subjects and to provide a source from which qualified officers may be obtained for the Armed Services of the United States.

Programs Offered. Each of the services offers a scholarship and two non-scholarship programs:

a) The scholarship program provides for those eligible and selected to receive scholarship assistance for a period up to four years to include all tuition, fees, books, and laboratory expenses. The cadet/midshipman will also be provided with uniforms required for participation and will receive subsistence allowance at the rate of $50 per month.

b) The four-year nonscholarship program provides for those qualified and enrolled to receive uniforms required for participation as a cadet/midshipman, books for military science subjects, and during the Advanced training phase (the third and fourth years) subsistence allowance at the rate of $50 per month, not to exceed twenty months.

c) The two-year nonscholarship program permits direct entry into the Advanced Course by attending summer training as substitution for the Basic Course. The cadet/midshipman will receive uniforms, books for military science subjects, and retainer pay at the rate of $50 per month, not to exceed twenty months.

Conditions of Enrollment. A student who enrolls in the scholarship program or in the Advanced Course of the nonscholarship programs must enlist in a reserve component of an armed force under the jurisdiction of the Secretary of the Military Department concerned and for the period prescribed by the Secretary. In addition, the student will contract (with the consent of his parents or guardian if he is a minor) with the Secretary of the Military Department concerned, or his designated representative to serve for the period prescribed by the Secretary.

Those students in the scholarship program and Advanced Course students in the nonscholarship programs who for reasons beyond their control or who, without intent to defraud the government, or who do not willfully violate the terms of their contract will, if disenrolled from the program, and upon the student's election, also be discharged from their enlisted reserve status at the same time. Students who willfully evade the terms of their contract, or complete the program and decline to accept a commission when tendered, may be called to active duty in their enlisted grade for a period not to exceed four years if in the scholarship program or two years if in the nonscholarship program.

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.

An engineering freshman may drop, without record, the basic nonscholarship courses during the College of Engineering approved drop period. For drop procedures after the approved drop period refer to particular ROTC department.

Air Science

Department Office: 154 North Hall

General Information. The Department of Air Science offers a program of studies designed to prepare selected male officer candidates for a professional career 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 United States Air Force, of current and projected aerospace weapons systems, and of officer leadership and management responsibilities and skills. Classroom activities throughout the program emphasize the development of imaginative and communicative skills by the participation of all members in group discussions, panel presentations, debates, individual reports, and other dialogue processes.

Students may enroll in either the four-year or the two-year program. A limited number of Financial Assistance Grants (scholarships), covering all tuition, fees, and books, are available on a competitive basis for cadets in the four-year program only. These scholarships are offered only to cadets in the sophomore, junior and senior year, based on their Air Science and general academic record in the preceding years. The two-year program enables transfer students and others to prepare themselves for Air Force careers with a lesser expenditure of course time.

Flying Activities. Qualified senior-year cadets desiring active service pilot training receive in a Flight Instruction Program approximately 36 hours of dual/solo light-plane instruction under a licensed civilian instructor, with the opportunity also to earn a private pilot's license. They receive approximately 12 hours of "ground school" work. When possible, local area orientation flights and overnight flights to Active Air Force bases are made to familiarize all cadets with Air Force life.

Requirements for Enrollment. Incoming male students, who are physically qualified citizens of the United States (or will become citizens during the fourth term) who can complete eight terms of air science prior to receiving their degrees, and who will meet all requirements for commissioning prior to their 28th birthday, may enroll in the four-year program on a nonscholarship basis. Male students enrolled in the University, or male transfer students interested in the two-year program, should contact the Professor of Air Science as early as possible before March 1 prior to fall enrollment to schedule attendance at a Field Training Course conducted during a 6-week period at an Air Force base prior to attendance for the fall term. Students with prior military service may enroll above the entry level, based upon evaluation of such military service by the Professor of Air Science.

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 Program as late as the first term of the junior year. Transfer students already in the AFROTC Program will be accepted at their level of training through prior concurrence with the Department of Air Science. 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.

Conditions of Enrollment. Enrollment in basic air science courses is voluntary. Students enrolled in Air Science 101, 102, 201, or 202 may drop at any time allowed by the general rules of the college. When a student enters the advanced program (Air Science 301, 302, 401, 402), he assumes a contractual obligation to complete the program, accept a commission, and serve on active duty as an officer.

Monetary Allowances. The scholarship program provides for tuition, books, and fees plus $50 per month subsistence allowance. Advanced cadets (third and fourth Air Science years) who are not on Air Force scholarships receive an allowance of $50 per month. Additional pay and travel allowances are provided for attendance at the Field Training Course.

Uniforms and Books are furnished to all 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 and is refunded when air service courses are terminated.

Selective Service Deferment. Cadets may request military deferment after the first term of enrollment in the Air Force ROTC Program. Deferment of a cadet may be continued as late as one year beyond the completion of the fourth year of air science provided the cadet is still working to earn his degree and commission.

Commissions in the Air Force. Cadets completing the Program and receiving a baccalaureate degree from the University are commissioned as second lieutenants in the United States Air Force. These new officers are then called into active duty with the Air Force for a period of four years for non flying officers and a five year period for pilots and navigators after completion of flight school. This active duty can be served in any of approximately thirty Officer Utilization Fields, ranging from jet pilot through a wide range of technical fields, such as missile operations, weather, research and development, communications-electronics, avionics, aircraft maintenance, civil-engineering, transportation, logistics, and intelligence, and including a broad selection of managerial and training areas, such as administrative services, accounting and finance, personnel, statistics, manpower management, education and training, investigations, air police, and information services. Advanced education or technical training for these career areas may be obtained on active duty at Air Force expense. Cadets with a distinguished undergraduate record may apply for commission as a regular officer upon graduation. Those who do not receive a regular commission upon graduation may compete for such a commission while in their initial year of active duty.

Extracurricular Activities. Selected cadets may become members of the local chapter of the national Arnold Air Society. Qualified cadets may participate in tri-service honorary organizations.

Courses Offered in Air Science

101. World Military Systems. I. *(1).*
Lecture, 1 hour a week; Cadet Corps activities, 1 hour a week.
Primary and secondary factors of aerospace power; types of modern conflict; employment of aerospace forces. Customs and courtesies of military organizations; fundamentals of military procedures.

102. World Military Systems. II. *(1).*
Lecture, 1 hour a week; Cadet Corps activities, 1 hour a week.
Organization of the Department of Defense and of the U.S. Air Force; roles of

the major air commands; professional opportunities in the Air Force. Development of military proficiency.

201. World Military Systems. I. *(1)*.
Lecture, 1 hour a week; Cadet Corps activities, 1 hour a week.
U.S. Army and Navy; joint doctrine and operations. Analysis of the NATO, CENTO and SEATO alliances from two standpoints: (1) strengths and weaknesses (political, military, economic, and psycho-social) of the countries individually and collectively; (2) the present and probable future threats facing these alliances. Development of leadership ability in Cadet Corps activities.

202. World Military Systems. II. *(1)*.
Lecture, 1 hour a week; Cadet Corps activities, 1 hour a week.
Analysis of the U.S.S.R., Communist China and the Warsaw Pact nations: (1) strengths and weaknesses (political, military, economic, and psycho-social) of these countries; (2) their political-military doctrines and the threats posed to the Free World. Discussion of general problems of war and peace, with special consideration to the causes of war and to new opportunities in the search for peace. Continued development of individual leadership skills.

301. Development of Aerospace Power. I. *(2)*.
Seminar, 3 hours a week; Cadet Corps activities, 1 hour a week.
History of airpower; development of doctrine governing the employment of aerospace forces; the U.S. defense establishment; concepts and doctrines governing employment of aerospace forces in the current world situation. Experience in the duties and responsibilities of a junior officer.

302. Development of Aerospace Power. II. *(2)*.
Seminar, 3 hours a week; Cadet Corps activities, 1 hour a week.
Evolution of the space program; the effects of solar geography on the space programs; 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. Continued development of officer skills in Cadet Corps activities.

401. The Professional Officer. I. *(2)*.
Seminar, 3 hours a week; Cadet Corps activities, 1 hour a week.
The military professional; problem solving techniques; principles and techniques of leadership and human relations. Experience in planning and directing activities of the Cadet Corps.

402. The Professional Officer. II. *(2)*.
Seminar, 3 hours a week; Cadet Corps activities, 1 hour a week.
Principles and functions of management; the military justice system; duties and responsibilities of a junior officer. Further development of leadership and management skills in Cadet Corps activities.

403. Weather and Navigation. I. *(1)*.
Lecture/practicum, 2 hours a week.
Principles of weather and aerial navigation. (Required of all participants in the Flight Instruction Program. Such participants must enroll in *both* A. S. 401 and A. S. 403.)

Military Science

Professor Reynolds, Assistant Professors Copeland, Fanning, Hallock, McVeigh, Wandke, and Instructors Bergin, Finley, and Taylor. 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, 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 terms of physical education. A cadet enrolled in the College of Engineering may drop the basic nonscholarship course, if he so desires, during the first six weeks of the first term. A cadet who remains in the basic ROTC program after this dropout period is expected to complete four terms of ROTC. This requirement may be waived in exceptional circumstances; for example, physical, financial, or academic reasons.

Entrance into the advanced program (junior and senior years) is on an invitational basis, the cadet having the option to accept or decline. Among the factors considered for entry into the advanced course are demonstrated leadership potential and academic record. In order for a cadet to enter the advanced program (junior and senior years) he must have completed the basic program (freshman and sophomore years) or six weeks basic training camp in the term between the sophomore and junior years at an Army Basic Training Camp. Those cadets who desire to enter the advanced course by attendance at the 6-week basic summer camp should contact the Professor of Military Science, room 131, North Hall, as soon as possible after the beginning of the winter term. A cadet having accepted the advanced program is required to enlist in the reserve and to sign a contract to (1) continue the ROTC program for the remaining four terms, (2) accept a commission if tendered, (3) serve his military obligation of active and reserve duty as required by law. Although the advanced course cadet is required to enlist in the reserve, he is not required to attend weekly meetings or participate in reserve summer training. The purpose of this reserve enlistment is to prevent any student from defrauding the government by refusing to accept his commission when tendered, or by willfully evading his contract. It will have no effect on the cadet who enters and continues the program in good faith. Upon withdrawal for valid reasons, such as academic, physical or financial problems, the cadet may be discharged from his enlisted reserve status if he desires.

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 four years or longer if necessary. To date, no University of Michigan ROTC graduate has been denied his request for delay or extension of delay.

Scholarship Program. Recent ROTC legislation has provided for scholarship assistance to selected students in the four-year program. This program provides $50 a month plus all books, tuition, and lab fees. Interested cadets should see the Professor of Military Science, 131 North Hall, for further information.

Flight Program. Qualified senior cadets may apply for the Army Flight Instruction program. The program consists of approximately 36½ hours of light plane flying instruction, and 35 hours of ground school instruction. All instruction is taught by licensed civilian instructors at no cost to the cadet. Upon successful completion, the cadet may be awarded a private pilot's license.

Branch Assignments. In their senior year, cadets will be classified for branch assignments upon commissioning to one of fourteen branches in accordance with their preference, aptitude, curriculum, interest, physical condition, and the nationwide needs of the Army. In the past, 80 per cent of University of Michigan students have been granted their first preference; 90 per cent their first or second preference, 100 per cent have received their first, second, or third preferences. Branches in which a cadet may be commissioned are as follows: Armor, Artillery, Adjutant General's Corps, Army Intelligence and Security, Chemical Corps, Corps of Engineers, Finance Corps, Infantry, Medical Service Corps, Military Police Corps, Ordnance Corps, Quartermaster Corps, Signal Corps, and Transportation Corps.

Advanced Standing. Students with prior military service or prior ROTC training (high school or college) may receive advanced standing in the ROTC program. Transfer students from colleges without ROTC units may qualify for advanced standing by completion of summer training after their sophomore year. The many variables preclude a blanket statement of eligibility; thus, students should contact the Professor of Military Science, 131 North Hall, personally for advanced standing determination. Students who desire to qualify for advanced standing by attendance at summer training should contact the Professor of Military Science as soon as possible after the beginning of the winter term.

Pay and Allowances. Pay and allowances begin with enrollment in the third year of military science in the nonscholarship programs and amount to approximately $500 for each of the last two years. In the scholarship program the cadets receive $600 for each year for a maximum of four years plus tuition, books, and laboratory fees. In addition, the cadet receives approximately $220 plus travel expenses to and from the six-week summer camp, and a $300 uniform allowance after he is commissioned.

Uniforms, Texts, and Equipment. All ROTC cadets are furnished a uniform and Military Science 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 Team (range, rifle, and ammunition available without charge).

ROTC Band—winter term only, instruments furnished.

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

Scabbard and Blade—a national honorary.

Course of Instruction. The complete course of instruction is divided into four major blocks of instruction: (1) American Military History; (2) Operations, Tactics, and Techniques; (3) Logistics and Materiel; (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 to include "academic substitution." The effect of the substitution program is that it is far less demanding on the cadet's time and amounts to 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 terms 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. *(1).*
Five hours of instruction on organization of the Army and ROTC; ten hours of instruction on the M-1 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. American Military History. *Prerequisite: M.S. 102 or permission of P.M.S. (2).*
Twenty-seven hours of instruction on American military history; three hours 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.

202. Operations and Tactics. *Prerequisite: M.S. 102 or permission of P.M.S. (2).*
Fifteen hours of map and aerial photograph reading; fifteen hours of intro-

duction 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.

301. Military Teaching Principles. *Prereuisite: 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 conterinsurgency 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; eight two-hour periods of leadership laboratory. Leadership laboratory designed to stress leadership principles applicable to active duty situations.

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; two hours of map reading review; 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 Sisley; Associate Professor Hazard; Assistant Professors Brooks, Buehl, Kebschull, Obenshain, and Sloan; Instructors Hobbs, Crawford, Pappas, and Wilfong. 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 afloat training, 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.

Officer Candidates. NROTC offers a scholarship and two non-scholarship programs:

The scholarship program provides for those eligible and selected to receive scholarship assistance for a period up to four years to include all tuition, fees, books, and laboratory expenses. The midshipman will also be provided with uniforms required for participation and will receive retainer pay at the rate of $50 per month.

The four-year nonscholarship "contract" program provides for those qualified and enrolled to receive: uniforms required for participation as a midshipman, books for naval science, and during the advanced training phase (the third and fourth years) retainer pay at the rate of $50 per month, not to exceed twenty months.

The two year nonscholarship "contract" program permits direct entry into the Advanced Course by attending summer training as substitution for the Basic Course. The midshipman will receive uniforms, books for naval science subjects, and retainer pay at the rate of $50 per month, not to exceed twenty months.

A student who enrolls in the scholarship program or in the Advanced Course of the nonscholarship programs must enlist in a reserve component of an armed force under the jurisdiction of the Secretary of the Navy for the period prescribed by the Secretary. In addition, the student will contract, with the consent of his parents or guardian if he is a minor, with the Secretary of the Navy, or his designated representative, to serve for the period prescribed by the Secretary. Those students in the scholarship program and advanced course students in the nonscholarship programs who for reasons beyond their control or who, without intent to defraud the government, or who do not willfully violate the terms of their contract, will if disenrolled from the program, also be discharged from their enlisted reserve status at the same time. Students who willfully evade the terms of their contract, or complete the program and decline to accept a commission when tendered, may be called to active duty in their enlisted grade for a period not to exceed four years if in the scholarship program or two years if in the nonscholarship program.

Upon satisfactory completion of the requirements for a baccalaureate degree and the naval science requirements a midshipman must accept a commission, if tendered, in the regular or reserve component of the Navy or Marine Corps, and to serve on active duty for such period as prescribed by the Secretary of the Navy.

Candidates must be between seventeen and twenty-one years of age. In special cases students sixteen years of age may be enrolled in either of the nonscholarship programs. 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 and uncorrected by glasses and in all cases must be correctible to 20/20. For students who have an approved major in engineering, physics, chemistry, mathematics, meteorology, oceanography or statistics, vision requirements are waived as follows: All physical standards must be met except that visual acuity less than 20/40 but not less than 20/100 for each eye is acceptable, provided the vision is fully correctible to 20/20. Students applying in this category, may be considered for enrollment into the science and engineering (S&E) option of the "contract" NROTC Program.

All students are required to complete eight terms of naval science subjects. Candidates for Marine Corps commissions complete four terms of general naval science subjects and four terms of Marine Corps specialty courses.

A personnel management course taught by the civilian faculty of the University is required during one term.

Midshipmen in the scholarship program participate in three summer cruises of six to eight weeks' duration; midshipmen in the nonscholarship program participate in one six- to eight-week summer cruise. Marine candidates spend the third cruise period at the Marine Corps Schools, Quantico, Virginia.

Midshipmen in the scholarship program must satisfactorily complete one year of college mathematics and one year of college physics by the end of their sophomore year. Midshipmen in the nonscholarship program must have satisfactorily completed a sequence of mathematics through trigonometry in high school or one term of mathematics in college.

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).*
Introduction to basic Navy background, procedures, regulations, and organization, with emphasis on the junior officer duties and responsibilities. The last third of the term introduces Navy history and sea power.

102. Sea Power and Naval History. *Prerequisite: N.S. 101.* II. *(3).*
Continuation of Naval Science 101, developing historically the importance of sea power from 1775 to present. Emphasis on present day application of past developments in techniques, strategy, tactics, organization, and leadership.

201. Naval Engineering. *Prerequisite: N.S. 102.* I. *(3).*
Prvides a broad general concept of the fundamentals of naval engineering installations, including steam, diesel, nuclear power, gas turbines, and auxiliary plants, and ship stability.

202. Naval Weapons. *Prerequisite: N.S. 201.* 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.

301. Navigation. *Prerequisite: N.S. 202.* 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 afloat training.

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.

305. Study of Evolution of Art of War. *Prerequisite: NS. 202.* 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.

402. Principles and Problems of Leadership. *Prerequisite: N.S. Senior.* 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.

405. Amphibious Warfare. *Prerequisite: N.S. 202.* 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).

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 Department of 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 communication 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 recognition systems, 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 Department, Professor Arthur W. Burks, 3057 Administration Building.

Undergraduates desiring to specialize in the communication sciences should consult Assistant Professor Flanigan, the undergraduate program adviser.

Information and Control Engineering

Information and control 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, followed by special work in information and control 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: Info. and Cont. Eng. 500, Linear Systems I *(3)*; Info. and Cont. Eng. 570, Principles of Automatic Control I (2); Info. and Cont. Eng. 571, Automatic Control Laboratory I *(1)*; Info. and Cont. Eng. 530, Probability in Instrumentation *(2)*; Elec. Eng. 438, Electronics and Radio Communication *(4)*; Math. 448, Operational Methods for Systems Analysis *(4)*.

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.

Masters 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 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 terms.

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

M.S. in Aeronomy

Advisory Committee: Professor Jones, Associate Professors Epstein and Bartman, Assistant Professor Hays, Lecturer Fontheim

A candidate for the degree Master of Science in aeronomy is expected to hold a bachelor's degree and to have completed the requirements in mathematics and physics for the Bachelor of Science in Engineering Degree (Mathematics 316 and Physics 146 or their equivalent). The bachelor's degree may be one in any field of specialization.

The degree Master of Science in aeronomy requires a minimum of thirty hours of graduate studies, which must include Aerospace Engineering 464 and 465, Meteorology and Oceanography 564 and 565, and Electrical Engineering 595 and 895, or their equivalents, and at least six credit hours of mathematics. The remainder of the program is selected from cognate subjects, as approved by one of the graduate advisors, including offerings from the department of Aerospace Engineering, Astronomy, Electrical Engineering, Engineering Mechanics, Geology, Mathematics, Meteorology and Oceanography, and Physics.

M.S.E. in Aerospace Engineering and M.S. in Aerospace Science

Advisory Committee: Professors Eisley and Adamson; Associate Professor Sichel

A candidate for the M.S.E. degree will normally include in his program three to five advanced courses in aerospace 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 aerospace engineering may be selected to emphasize one or more of the following technical areas: gasdynamics (aerodynamics and propulsion), flight mechanics and control, and structural mechanics.

A candidate for the M.S. degree in aerospace science 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 selected courses in mathematics and physics and several courses in aerospace engineering. Up to four credit hours of nontechnical studies and up to five credit hours of directed study may be elected. The courses in aerospace engineering may be selected to emphasize one or more of the following technical areas: gasdynamics, flight mechanics and control, and structural mechanics.

M.S.E. in Chemical Engineering

Program Adviser: Professor York, 3215 East Engineering Building

The 30-hour requirement for the M.S.E. degree is customarily satisfied by a minimum of twenty-four hours of graduate course work, with grades of B or better, with the remainder being research credit with a grade of S. The course work must include at least fifteen hours in chemical and metallurgical engineering, including Chem.-Met. Eng. 541, 542 and one of the departmental graduate courses in thermodynamics, and excluding Chem.-Met. Eng. 690 and 692. Each student is encouraged to develop a program to fit his professional objectives and should consult with the graduate adviser in this matter. Each graduate student is required to engage in supervised teaching or research activities each full term he is enrolled.

A full range of courses is available in many special fields, particularly: biochemical engineering, catalysis, materials, petroleum refining and production, polymers, process dynamics, process and equipment design. A booklet describing the graduate program in more detail is available from the chairman of the Department of Chemical and Metallurgical Engineering.

M.S.E. in Civil Engineering

Program Adviser: Professor Brater

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

Faculty: Professors Burks (Chairman), Galler, Garner, Hok, Holland, Melton, Rapoport, and Swain; Associate Professors Arden, Lawler, and Pew; Assistant Professors Flanigan, Meyer, and Rosenberg; Lecturers O'Malley, Peck, and Reiter; Visiting Professor Muller

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

Students may be admitted to the M.S.E. degree program from any of the undergraduate engineering curriculums if accepted by the admissions 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 admissions committee, must be completed, including Mathematics 425 and 513, and Com. Sci. 400, 410, 475, 522, 530, 541, 550, and 580.

M.S.E. in Construction Engineering

Program Adviser: 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 requirement for this degree is the successful completion of at least thirty credit hours of graduate work, of which twelve credit hours must be in courses emphasizing construction. The remainder of the program will be selected in conference with the adviser along lines designed to best complement the student's ultimate objective.

M.S.E. in Electrical Engineering and M.S. in Energy Systems

Program Advisers: Professors Grimes, Kazda, Lawler, Macnee, Mouzon, and Sharpe.

A candidate for the M.S.E. 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.

A candidate for the M.S. degree in energy systems must present substantially the equivalent of a four-year program in engineering, including courses in engineering materials, fluid flow, thermodynamics, electrical circuits, electromechanical energy conversion, and physical electronics (required for Direct Conversion Area). Once a student has satisfactorily demonstrated his knowledge in these areas he will be admitted into the graduate program. The satisfactory completion of the requirements for the degree M.S. (energy systems) requires that the student complete the following courses: Math. 450 plus 2 graduate hours of mathematics, Mech. Eng. 471 and 535 or Chem.-Met. Eng. 430, Elec. Eng. 420 and 444 and Nuc. Eng. 400. The hours remaining after the above courses have been completed are to be selected in an area of specialization designated and approved by the program adviser. It is expected that the majority of these credits will be obtained in courses of the 500 (or higher) series level. *However, a student will not receive graduate credit for any course required in the undergraduate program at The University of Michigan corresponding to the program in which he receives his B.S. degree.*

Typical areas of specialization which are available to the candidate are listed below.

Control Systems: Elec. Eng. 445 or Info. and Cont. Eng. 570, and one or more of the following: Elec. Eng. 446, 547, 673.

Power Generation: (1) Nuclear: Nuc. Eng. 441, and one or more of the following: Nuc. Eng. 442, 555, 561; Chem.-Met. Eng. 573, 574, 579, 586. (2) Chemical Combustion: Mech. Eng. 432, 531; Chem.-Met. Eng. 439, and one or more of the following, Mech. Eng. 437, 496, 535 or Chem.-Met. Eng. 530, Mech. Eng. 571, 672, 573; Chem.-Met. Eng. 573, 574. (3) Hydraulic: Civ. Eng. 523, 529; and one or more of the following, Mech. Eng. 422, Civ. Eng. 524, 526. (4) Direct Conversion: Elec. Eng. 483, and one or more of the following, Chem.-Met. Eng. 510, Elec. Eng. 583, 688, Mech. Eng. 573.

Power Transmission and Utilization: Elec. Eng. 553, 554, and one or more of the following: Elec. Eng. 541, 542, 555, 557, 558.

Energy Systems Economics: Elec. Eng. 552 or Ind. Eng. 451, and one or more of the following: Ind. Eng. 472, Civ. Eng. 501, 531.

There will be special seminars in topics as required.

M.S. in Electrical Science

Program Adviser: Associate Professor R. J. Lomax

The objective of this program is to permit students whose early training is in disciplines other than electrical engineering and those trained in electrical engineering whose interests are in the scientific aspects, to obtain advanced training in electrical science.

An applicant seeking admission to the Master of Science program with a specialty in Electrical Science must have obtained the equivalent of a bachelor's degree in engineering, physical science, or mathematics. To obtain the degree he must complete a minimum of thirty credit hours, which may be adapted to his individual background and interests subject to departmental approval. This program must include Elec. Eng. 583, Elec. Eng. 620 or their equivalents, and a minimum of six hours of mathematics appropriate to the individual's program beyond Math. 450. A student may choose to specialize in one of the following: plasmas; radiation, propagation, and scattering; solid-state materials; microwave and quantum electronic devices; radio astronomy; modern optics. In general this program will include courses in electrical engineering, mathematics and physics, and selected courses from other departments and programs of the University.

M.S. in Systems Engineering-Electrical

Program Adviser: Associate Professor K. B. Irani

Systems Engineering in the Department of Electrical Engineering encompasses the transmission, conversion, and control of information and energy, as embodied in computer, communication, control, information, data processing, and power systems.

An applicant for admission to the Master of Science in Systems Engineering-Electrical program in the Department of Electrical Engineering must have the equivalent of a bachelor's degree in engineering, science, or mathematics. He must complete a program of thirty credit hours, which may be adapted to his individual background and interests, subject to departmental approval. Normally this program will include electrical engineering courses in linear, stochastic, and finite-state systems; systems technology courses offered in electrical engineering such as computers and information processing, communications, control, and energy systems; selected courses in mathematics; and selected courses offered by other departments and programs of the University. A student whose undergraduate training is inadequate for the particular option he wishes to elect will be permitted to make up his deficiency by additional course work.

M.S.E. in Engineering Materials

Graduate Adviser: Associate Professor W. F. Hosford, 4223 East Engineering.

The 30-hour requirement for this M.S.E. degree is customarily satisfied by a minimum of twenty-four hours of graduate course work, with grades of B or better, with the remainder being research credit with a grade of S. The course work must include: (a) nine credits in engineering or scientific principles and including such courses as Chem.-Met.Eng. 535, 552, 553, 570, 577, 636, or 650; (b) three credits in properties and utilization of metallic materials; (c) three credits in properties and utilization of ceramic materials; and (d) six credits in electives excluding Chem.-Met. Eng. 690 and 692. Each graduate student is required to engage in supervised teaching or research activities each full term he is enrolled. A booklet describing the graduate program in more detail is available from the chairman of the Department of Chemical and Metallurgical Engineering.

M.S.E. in Engineering Mechanics

Graduate Program Committee: Professors Debler, Chairman, Liu, McIvor, Yang

Students starting graduate study in engineering mechanics normally should have a preparation which is substantially the equivalent of the requirements for a bachelor's degree in engineering mechanics at The University of Michigan. This includes studies in mathematics and mechanics beyond the introductory level. In many cases applicants will have done their previous study in other branches of engineering or science. Generally, students from any of the usual undergraduate engineering degree programs and from nonengineering programs such as mathematics and physics will have had all or most of the desired preparation. If deficiencies exist, they may be made up in a manner prescribed by the departmental graduate program committee.

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 442, 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 Engineering

Program Adviser: Professor R. M. Thrall

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 including a thesis approved by the adviser. Approximately eighteen hours of this will be in the industrial engineering area.

A candidate for the M.S. degree in industrial engineering must present the equivalent of a bachelor's degree in recognized programs in any other engineering field, physics, or mathematics. He must complete in residence a minimum of thirty hours of graduate work. Approximately eighteen hours of this will be in the industrial engineering area. Candidates may be required to make up deficiencies in their preparation in statistics, linear programming, or computer programming without graduate credit.

M.S.E. and M.S. in Information and Control

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; Info. and Cont. Eng. 500, 530, 570, 630, and 670; and other courses approved by the committee on information and control engineering, including at least two laboratory courses. 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 information and control science is offered.

M.S.E. in Mechanical Engineering

Program Adviser: Associate Professor Winer, 225A West Engineering

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: Associate Professor W. F. Hosford, 4223 East Engineering.

The 30-hour requirement for this M.S.E. degree is customarily satisfied by a minimum of twenty-four hours of graduate course work, with grades of B or better, with the remainder being research credit with a grade of S. The course work must include fifteen hours in chemical and metallurgical engineering, including courses from the areas of physical, mechanical, and process metallurgy and excluding Chem.-Met. Eng. 690 and 692. Other courses are to be selected from the areas of physical, mechanical, and process metallurgy as approved by the adviser. Each student is encouraged to design his program to satisfy his special interest. Each graduate student is required to engage in supervised teaching or research activities each full term he is enrolled. A booklet describing the graduate program in more detail is available from the chairman of the Department of Chemical and Metallurgical Engineering.

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. 404 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: Professor Michelsen

To be admitted as an applicant for this degree the student must satisfy the graduate committee of the department that he has completed preparation equivalent to the undergraduate degree requirements at this University. The undergraduate degree does not have to be in the field of Naval Architecture and Marine Engineering. The student, however, is expected to have completed the basic mathematics and physics curriculum of the Bachelor of Science in Engineering degree.

Requirements for the degree include 30 credit hours of graduate studies, approved by the graduate adviser, including at least 10 credit hours of course work in Naval Architecture and Marine Engineering exclusive of those required for the degree of B.S.E. (Nav. Arch.-& Mar.E.), a minimum of 5 credit hours of mathematics beyond undergraduate degree level, and cognate subjects. A thesis may also be required. If the applicant's undergraduate work is in a field other than naval architecture and marine engineering, or taken at a non-accredited school, the program adviser may require that he first enter the College of Engineering as an undergraduate special student for one or more terms.

It is possible to obtain the Master of Science in Engineering degree in the combined fields of Naval Architecture and Marine Engineering, and another engineering field, after the student has first been admitted to one department. To do so he must be able to present an acceptable study program endorsed by the program advisers of the two departments involved, showing a minimum of 36 hours of graduate-level courses. The program outline must then be presented to the Dean of the Graduate School for final approval.

M.S.E. in Nuclear Engineering and M.S. in Nuclear Science

Program Adviser: Professor Kammash

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 who wish to work on nuclear energy development. The undergraduate preparation required for these programs is listed under Special Fields.

The requirements for the master's degree are thirty hours of completed course work including twenty hours from nuclear engineering with four hours of laboratory in this department or the equivalent. An average of B must be maintained in the nuclear engineering courses. At least two cognate courses must be taken. All students are required to complete a one-term research or design problem under Nuc. Eng. 599 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 nuclear engineering 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 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 complement the student's ultimate objective.

M.S.E. in Water Resources Engineering and M.S. in Water Resources Science

Program Adviser: Associate Professor Weber

Interdisciplinary programs of advanced study in water resources engineering and in water resources science are centered in the Department of Civil Engineering. The program leading to the degree M.S.E. in Water Resources Engineering is open to qualified candidates with a Bachelor of Science degree in any of the generally recognized fields of engineering. A program leading to the M.S. in Water Resources Science is available for individuals who hold a Bachelor of Science degree in some discipline other than engineering—*e.g.,* chemistry, biology, bacteriology, mathematics, etc.—and who otherwise qualify to pursue advanced study in one or more of the areas of specialization related to a particular phase of water resources analysis, development use, or water quality and pollution control.

Candidates for the degree M.S.E. must complete a minimum of thirty hours of graduate-credit work, planned in consultation with the program adviser, constituting an integrated program in water resources engineering. Normally at least fifteen hours of the required thirty will be selected from courses available within the Department of Civil Engineering. Water serves many economic and social needs, and the water resources engineering program is flexible enough to meet the interests and requirements of the individual within the overall objective of providing both increased depth in traditional physical, chemical, and biological sciences applicable to the engineering solution of problems in water resources and, at the same time, ample opportunity to gain new insights with study in cognate areas.

The degree M.S. in Water Resources Science, under the general administrative direction of the University Water Resources Committee, is intended primarily for: (1) chemists who wish to specialize in Water Chemistry; (2) biologists or bacteriologists who wish to specialize in Aquatic Biology; and (3) mathematicians who wish to specialize in Water Resources Systems Analysis and Design. A minimum of thirty six hours of graduate credit is required to qualify for the degree. This will normally consist of six hours in courses designed to orient the student to the broad field of water resources, fifteen hours in core courses in his scientific specialization, nine hours of science electives to meet the student's special needs, and six hours of laboratory or field research. No thesis is required but the student will prepare a written scientific report covering his research problem. Each candidate for the degree M.S. in Water Resources Science will plan his program in consultation with the program adviser.

Professional Degrees

Programs are offered which lead to the following professional degrees:

Aerospace Engineer—Aerospace E.

Applied Mechanics Engineer—App.M.E.

Chemical Engineer—Ch.E.

Civil Engineer—C.E.

Electrical Engineer—E.E.

Industrial Engineer—Ind.E.

Information and Control Engineer—Info. and Cont.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 result 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.

Each student must demonstrate reading competence in one professionally acceptable language, in addition to English, before he can be accepted as a candidate for the PhD degree. The language will be chosen, in consultation with the student, by the department chairman or program chairman or his designated representative. French, German, Russian, or any other language acceptable to the department chairman or program chairman may be offered. Individual departments or programs may have requirements for more than reading competence or more than one language.

The requirement for demonstration of reading competence may be satisfied in any one of the following ways:

1a. By courses—French, German, or Russian 112 completed with a grade of B or better.

1b. By courses in various languages judged of equivalent difficulty by the Graduate School.

2. By reading examination administered by the Graduate School.
3. By reading examination administered by the department.
4. By the Graduate Foreign Language Examination (Educational Testing Service) in French or German only.

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.

See page 33 for definitions relating to the University's term. Time schedules are 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.

When they appear, Roman numerals in light-face type indicate the time in which the department concerned plans to offer the course: I, fall; II, winter; III, spring-summer—III*a,* spring half; III*b,* summer half (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.

Aerospace Engineering

Department Office: 1077 East Engineering

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

314(Eng. Mech. 314). Structural Mechanics I. *Prerequisite: Eng. Mech. 210 or 319.* 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 col-

umns. Introduction to matrix methods of deformation analysis; structural dynamics. Lectures and laboratory.

415. Principles of Structural Mechanics. *Prerequisite: Eng. Mech. 210 or 319.* 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.

421. Topics in Fluid Mechanics. *Prerequisite: Aero. Eng. 420 or equivalent. (3).*
Topics include free surface phenomena, flow separation, flow in tubes, lubrication, flow in a gravity-free environment. The objective of the course is to extend the student's background in gas dynamics to the fundamental aspects of other fluid phenomena of importance in aerospace and other industrial applications. Lectures and demonstrations.

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.

445. Principles of Mechanics of Flight. *Prerequisite: Math. 316. (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.

464(Meteor.-Ocean. 464). Aeronomy I. *Prerequisite: senior or graduate standing. (3).*
An introduction to physical processes in the upper atmosphere. The structure of the upper atmosphere: density, temperature, composition, and winds; acoustical propagation and visible phenomena; the ionosphere. The physical basis of the techniques of satellite meteorolgy: solar, terrestrial, and atmospheric radiation processes including transfer and heat balance.

465(Meteor.-Ocean. 465). Aeronomy II. *Prerequisite: Aero. Eng. 464. (3).*
High altitude observations of aeronomical and meteorological phenomena. The physical basis and need for aerodynamic, mass spectrometric, and radiative experiments. Sensor characteristics. Current balloon, aircraft, rocket, and satellite techniques.

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. *Prerequisite: Aero. Eng. 314 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.

483. Aerospace System Design. *Prerequisite: Aero. Eng. 314 and 441 and preceded or accompanied by Aero. Eng. 430.* I and II. *(4).*
Aerospace system design, analysis and integration. Consideration of launch facilities, booster systems, spacecraft systems, communications, data processing, and project management. Lectures and laboratory.

490. Directed Study. *(To be arranged).*
Individual study of specialized aspects of aerospace engineering. Primarily for undergraduates.

510. Energy Theorems and Matrix Methods in Structural Mechanics I. *Prerequisite: Aero. Eng. 414 or Eng. Mech. 411 or 412. (3).*
The principle of virtual work and the theorems of minimum potential and minimum complementary energy. Variational calculus, the Rayleigh-Ritz method, Galerkin's method. Solution by finite differences. The matrix force and displacement methods. Applications to simple structures and structural elements such as beams, frames, and plates. Static and dynamic problems.

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 de-

flection and buckling. Brief discussion of material properties at elevated temperature, creep, thermal stress effects on structural stiffness.

520. Gasdynamics I. *Prerequisite: Aero. Eng. 420 or 425 or equivalent. (3).*
Gasdynamics at an intermediate level: Thermodynamics; the conservation equations; vorticity theorems; unsteady one-dimensional flow; the method of characteristics; stationary and moving shock waves; two-dimensional steady flow including method of small perturbations.

521. Experimental Gasdynamics. *Prerequisite: Aero. Eng. 330 and 420 or equivalent. (3).*
Experimental methods in modern gasdynamics; physical principles and interpretation. Shop practice and theory of instrument design; mechanics, electronics, and optics. Measurement of velocity, pressure, density, temperature, composition, energy and mass transfer in fluids and plasmas. Transducers and laboratory instrumentation in gasdynamic research.

522. Gasdynamics II. *Prerequisite: Aero. Eng. 520. (3).*
Similarity laws for two- and three-dimensional high speed flows; two-dimensional incompressible flows by conformal mapping; examples of flows with viscosity, including simple cases of compressible boundary layer flow; introduction to electromagnetic theory, and the equations for magnetohydrodynamic flow.

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. Introduction to Gaskinetics and Real Gas Effects. *Prerequisite: Aero. Eng. 420 or permission of instructor. (3).*
A study of some modern topics of flow problems not covered in the traditional gasdynamics of ideal gases: concepts of gaskinetics, aerodynamics of free molecules, shock transition layer, real gas effects, high temperature effects, multicomponent flows, etc.

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: Eng. Mech. 343. (4).*
Kinematics of motion, particle dynamics, orbital motion and calculation of orbital parameters, Lagrange's equation. 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.

541. Orbital and Re-entry Mechanics of Spacecraft. *Prerequisite: Aero. Eng. 441.* I. *(3).*
The study of motion of spacecraft in a vacuum and in the atmosphere with emphasis on preliminary mission planning. Analysis of trajectories in sub-

orbital, orbital, lunar, and interplanetary operations. Aerodynamic forces and heating characteristics and their effect on the selection of flight paths during entry into planetary atmospheres.

543. Structural Dynamics. *Prerequisite: Aero. Eng. 414 or 540. (3).*
Natural frequencies and mode shapes of elastic bodies. Nonconservative elastic systems. Structural and viscous damping. Influence coefficient methods for typical flight structures. Response of structures to random and shock loads. Lab demonstration.

544. Aeroelasticity. *Prerequisite: Aero. Eng. 414 or 540. (3).*
An introduction to aeroelasticity. Vibration and flutter of elastic bodies exposed to fluid flow. Static divergence and flutter of airplane wings. Flutter of flat plates and thin walled cylinders at supersonic speeds. Oscillations of structures due to vortex shedding.

564(Meteor.-Ocean. 564). The Stratosphere and Mesosphere. *Prerequisite: Meteor.-Ocean. 464 or permission of instructor.* I. *(3).*
The physical, chemical and dynamical properties of the atmosphere between the tropopause and the turbopause. Among the topics covered are the heat and radiation budgets, atmospheric ozone, stratospheric warmings, the biennial stratospheric oscillation, airglow.

565(Meteor.-Ocean. 565). Planetary Atmospheres. *Prerequisite: Meteor.-Ocean. 464 or permission of instructor.* II. *(3).*
The composition, structure and dynamics of extraterrestrial atmospheres; origin and evolution of planetary atmospheres; detailed treatment of the atmospheres of Mars and Venus; theoretical and empirical results, including planetary observations by space probes.

590. Directed Study. *(To be arranged).*
Individual study of specialized aspects of aerospace engineering. Primarily for graduates.

610. Energy Theorems and Matrix Methods in Structural Mechanics II. *Prerequisite: Aero. Eng. 510. (3).*
Application of energy methods and matrix methods to shells, built-up shell-type structures, and problems in three-dimensional elasticity. Nonlinear problems in structural mechanics that arise from large amplitude deformations. Static and dynamic problems.

620. Dynamics of Viscous Fluids. *Prerequisite: Aero. Eng. 520 or permission of instructor. (3).*
Navier-Stokes equations; low Reynolds number flows; incompressible and compressible laminar boundary layers; boundary layer stability and transition to turbulence; turbulent boundary layers, wakes, and jets.

621. Dynamics of Compressible Fluids. *Prerequisite: Aero. Eng. 520. (3).*
Theory of characteristics; shock-wave phenomena; interaction problems; hodograph transformation; transonic flow.

622. Hypersonic Aerodynamics. *Prerequisite: Aero. Eng. 520. (3).*
Inviscid flow past thin bodies at high Mach number; blunt-body methods; blastwave theory; viscous interaction, nonequilibrium flows.

624. Linearized Aerodynamic Theory. *Prerequisite: Aero Eng. 520. (3).*
Application of conformal mapping in the study of thin airfoils; three dimensional subsonic and supersonic wing theory; forces acting on oscillating wings; slender-body theory; higher approximations.

625. Methods of Theoretical Aerodynamics. *Prerequisite: Aero. Eng. 520 or permission of instructor. (3).*
Application of methods for solving partial differential equations which arise in aerodynamics problems. Subsonic and supersonic wing theory, sound waves, viscous flows, boundary-layer theory, shock waves. Emphasis on the use of fundamental solutions and superposition in linear problems and asymptotic methods in nonlinear problems. Similarity solutions, characteristics.

627. Continuum Theory of Fluids. *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.

628. Statistical Theory of Fluids. *Prerequisite: Aero. Eng. 532 or permission of instructor. (3).*
A study of the flows of neutral and charged particles from the viewpoint of kinetic theory; Chapman-Enskog theory of transport phenomena, dynamics of rarefied gases, plasma kinetics without external magnetic field, plasma oscillations and Landau damping, micro-instabilities, plasma interactions.

632. Gas Flows with Chemical Reactions. *Prerequisite: Aero. Eng. 532, 620 or permission of instructor. (3).*
Thermodynamics of gas mixtures, chemical kinetics, conservation equations for multi-component reacting gas mixtures. Deflagration and detonation waves. Nozzle flows and boundary layers with reaction and diffusion.

641. Flight Mechanics of Space Vehicles II. *Prerequisite: Math. 450, Aero. Eng. 540.* II. *(2).*
Hamilton's equations and Hamilton-Jacobi theory. Orbit determination and the mehods of special and general perturbations. Transfer orbits and orbit modification.

650. Computational Methods for Flight Simulation. *Prerequisite: Aero. Eng. 540 and Info. and Cont. Eng. 510 or Elec. Eng. 465. (2).*
Equations of motion for aircraft and aerospace vehicles. Axis systems and axis transformations including body, stability, flight-path, navigational, and inertial axes. Euler angles, direction cosines, and quaternions. Simulation of flat earth trajectories, low-eccentricity orbits, lunar and planetary trajectories. Use of conservation laws and constraint methods. Mechanization in six degrees of freedom using analog, hybrid, and digital computers.

651. Computation of Aerospace Trajectories. *Prerequisite: Aero. Eng. 641 or equivalent. (2).*
Error analysis of numerical integration methods. Comparison of Cavell's method, Enke's method and variation-of-parameters in terms of accuracy and convenience. MAD programming of integration methods. Student programming and solution of trajectory problems.

670. Guidance of Space Vehicles and Missiles. *Prerequisite: Info. and Cont. Eng. 670 or equivalent. (2).*
Principles of space vehicle and ballistic missile guidance systems in two and three dimensions, including departure, rendezvous, orbital transfer, and reentry problems. Mechanization by inertial and other means. Analysis of navigational homing systems.

671. Guidance and Control Laboratory. *Prerequisite: preceded or accompanied by Aero. Eng. 670 and Aero. Eng. 674. (2).*
Simulation of aircraft, missile, and space vehicle autopilot systems on analog and hybrid computer systems. Digital and analog solution of missile and space vehicle guidance problems.

674. Control of Aircraft, Missiles, and Space Vehicles. *Prerequisite: Info. and Cont. Eng. 670 or equivalent. (2).*
Analysis and synthesis of autopilots for aircraft and cruise-type missiles. Design of thrust-vector control systems including effects of elastic structures and fuel sloshing. Attitude control systems for space vehicles; mechanization using jet thrusters and inertia wheels; gravity gradient moments.

721. Turbulence. *Prerequisite: Aero. Eng. 620 or permission of instructor. (3).*
Physical and mathematical description of turbulence in boundary layers, wakes, jets, and behind grids; turbulent fields; theories for turbulent mass, momentum, heat, and particle diffusion.

726. Introduction to Plasma Dynamics. *Prerequisite: permission of instructor. (3).*
Physical properties of a plasma; particle orbit theory; collective phenomena in a plasma; kinetic equations for a plasma; instabilities; transport phenomena and derivation of the magneto hydrodynamic equations.

729. Special Topics in Gasdynamics. *Prerequisite: permission of instructor. (To be arranged).*
Advanced topics of current interest.

730. Energy Transfer in High Temperature Gas Flows. *Prerequisite: Aero. Eng. 532 and 620 or permission of instructor. (3).*
Energy transfer processes as related to high temperature gas flows; unsteady heat conduction, convection in non-reactive and reactive flows, transport properties, ablation and gaseous radiation.

740. Flight Mechanics of Space Vehicles III. *Prerequisite: Aero. Eng. 540 or equivalent, Info. and Cont. Eng. 670.* II. *(3).*
Review of necessary conditions in ordinary minimization and variational problems. Theory of minimum-fuel drag-free trajectories in uniform and inverse-square gravitational fields. Optimal trajectories in the atmosphere. Sensitivity in optimal trajectories. Computation methods for optimum trajectories, including the gradient method, iterative solutions of the Euler-Lagrange equations, finite-difference approximations, and direct methods.

800. Seminar. *(To be arranged).*

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 altitude 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—School of Business Administration

Office: 150 Business Administration

Professors Danielson, Dixon, Dykstra, Gies, D. Jones, Leabo, Pilcher, Rewoldt, Ryder, Schmidt, Southwick, and Spivey; Associate Professor Wilhelm; Assistant Professors Brophy and Miller.

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 500 or above 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. The following are courses of particular interest to engineering students:

Business Economics and Public Policy
300. Economics of Enterprise. *(3).*

Accounting and Information Analysis
271. Principles of Accounting I. *(3).*
272. Principles of Accounting II. *(4).*

Administration, Organization, and Policy
*300. Behavioral Theory in Management. *(3).*
311. Production Management. *(3).*

Finance
300. Money and Bank. *(3).*
301. Business Finance. *(3).*

Industrial Relations
*315. Management of Personnel. *(3).*
322. Management-Union Relations. *(3).*

* Not Allowed for credit in Ind. Eng. Program.

Law, History, and Communication
305. Business Law. *(3).*
306. Business Law. *(3).*

Marketing
300. Marketing Principles and Policies. *(3).*

Statistics and Management Science
300. Introduction to Probability. *(3).*
301. Introduction to Statistical Inference. *(3).*

Chemical and Metallurgical Engineering

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200. Introduction to Engineering Calculations. *Prerequisite: a university course in chemistry or physics. (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. (5).*
Development of fundamental thermodynamic property relation and complete energy and entropy balances. Analysis of heat pumps and engines, and use of combined energy-entropy balance in flow devices. Calculation and application of total and partial properties in physical and chemical equilibria.

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.) (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, magneti, and radiation). Two lectures and two recitations.

341. Rate Processes I. *Prerequisite: Chem.-Met. Eng. 200. (3).*
A study of momentum, 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. (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. (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. (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.

351. Structure and Properties of Materials. *Prerequisite: Chem.-Met. Eng. 250 or equivalent. (3).*
The basic operations in materials such as solidification, sintering, deformation, and age-hardening, with emphasis on the laboratory methods involved in studying the effects of these operations on structures and properties. (To be offered 1969.)

371. Physical Metallurgy I. *Prerequisite: Chem.-Met. Eng. 351 and Chem. 266. (3).*
Properties and behavior of commercial metals and alloys, including hardenability, corrosion, strengthening mechanism and microstructural control. (To be offered in 1969-70.)

400. Chemical Engineering Calculations. *Prerequisite: Math. 316 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. (3).*
Basic relations among thermodynamic properties; entropy balance and concept of availability. Physical and chemical equilibrium, solutions, and equilibrium stage calculations.

434(Civ. Eng. 580). (Microb. 434). Microbiology for Engineers. *Prerequisite: Math. 316, Chem. 225, and senior standing, or permission of instructor. (3).*
Principles and techniques of microbiology with an introduction to their application in the several fields of engineering. Lectures and laboratory.

439(Mech. Eng. 439). Combustion and Air Pollution Control. *Prerequisite: permission of instructor. (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. (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.

450. Engineering Physical Ceramics. *Prerequisite: preceded or accompanied by Chem. 266 and Chem.-Met. Eng. 350. (4).*
The nature, properties, processing, and application of ceramic materials.

451. Introduction to High Polymers. *Prerequisite: organic chemistry, physical chemistry, or permission of instructor. (4).*
Preparation, properties, and utilization of polymeric materials. Lectures, recitation, and laboratory.

530. Thermodynamics III. *Prerequisite: Chem.-Met. Eng. 430. (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. (3).*
Laws of thermodynamics applied to metallurgical systems. Introduction to statistical mechanics.

536. Metal Reactions in Melting and Refining. *Prerequisite: Chem. 266, Chem.-Met. Eng. 489. (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. (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. (3).*
A continuation of Chem.-Met. Eng. 541, with stress on mass transfer and chemical kinetics.

543. Separations Operations. *Prerequisite: Chem.-Met. Eng. 541. (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.

548. Dynamics of Biochemical Systems. *Prerequisite: Chem. 226, 266, and a course in microbiology. (3).*
Colloidal phenomena in biological systems, mechanisms of transport through membranes, physical chemical properties of biological materials, kinetics of growth processes, enzyme catalysis, natural control mechanisms, engineering applications of biochemical phenomena.

550. Solid-State Kinetics. *Prerequisite: physical chemistry or a course in solid-state physics. (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. (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.

552. Process Ceramics. *Prerequisite: one 300 or 400 level course in materials, and Chem.-Met. Eng. 230 or equivalent. (3).*
Principles and practice of ceramic fabrication process; microstructure development, and special ceramic forming techniques.

553. Physical Ceramics. *Prerequisite: two 300 or 400 level courses in materials, or permission of the instructor. (3).*
Atomic arrangements in ceramic materials; phase relationships in ceramic systems; correlation with physical properties.

558. Physical Polymers. *Prerequisite: Chem.-Met. Eng. 350 or Chem.-Met. Eng. 451. (3).*
Structure and properties of polymers as related to their composition, annealing and mechanical treatments. Topics include creep, stress-relaxation, dynamic mechanical properties, viscoelasticity, transitions, fracture, impact, dielectric, permeation and morphology.

560. Electron Microscopy. *Prerequisite: senior or graduate standing in engineering or science. (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. (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. (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. (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. (3).*
Ternary systems, phase transformations, plastic deformation, and fracture. Lecture, recitation, and laboratory.

572. X-ray Diffraction I—Fundamentals. *Prerequisite: Chem.-Met. Eng. 472 or permission of instructor. (3).*
Mathematical and physical principles of kinematic diffraction. Advanced crystallography, Fourier analysis, reciprocal space and single crystal x-ray techniques, and the application of diffraction to studies of solids, liquids, and gases.

573. Corrosion of Metals and Alloys. *Prerequisite: Chem.-Met. Eng. 479 or equivalent. (3).*
Fundamentals involved in choosing a metal for use in a corroding medium or at elevated temperatures.

455. Theory of Solids. *Prerequisite: Chem.-Met. Eng. 250, and Chem. 266 or a course in modern physics. (3).*
Dislocation theory, electron theory of metals, semiconduction, dielectrics, optical behavior, and magnetism. (To be offered in 1970.)

460. Engineering Operations Laboratory. *Prerequisite: Chem.-Met. Eng. 342. (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. (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. (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. (3).*
Radiography, investigation of welds and castings; diffraction studies of metals and alloys. Lectures, recitation, and laboratory.

475. Fundamentals of Metal Casting. *Prerequisite: a course in physical chemistry, Mech. Eng. 381, or Mech. Eng. 550. (3).*
Application of chemistry and physics to the liquid state and solidification of castings. Quantitative application of thermodynamics, heat transfer, and fluid mechanics to the design problems associated with the casting process. Experimental work includes solidification rates, flow of liquid metal, fluidity, physics of mold design, slag-metal-gas equilibria, and a short research problem.

477. Metallurgical Operations. *Prerequisite: Chem.-Met. Eng. 470 or 479 or 576. (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. (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. (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 I. *Prerequisite: Chem.-Met. Eng. 342. (3).*
Application of mathematics, chemistry, and physical, natural, and engineering sciences to the design of chemical processes and engineering systems.

482. Chemical Process Design II. *Prerequisite: Chem.-Met. Eng. 480 or 481 or 489. (1).*
Assigned problem in chemical engineering process design as specified by the instructor, or the annual AIChE Student Contest Problem.

484. Biochemical Technology. *Prerequisite: 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. 227 and Chem.-Met. Eng. 342 or 448. (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. (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.

490. Directed Study, Research and Special Problems. *(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.

500. Advanced Chemical Engineering Calculations. *Prerequisite: Chem.-Met. Eng. 400 and courses in differential equations and operational mathematics with concurrent registration in latter permitted. (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. (3).*
Application of numerical and computer-oriented methods to the correlation of experimental data, and the solution of the problems in the fields of flow through porous media and equipment, staged operations, reaction kinetics, and heat transfer.

510. Electrochemical Engineering. *Prerequisite: Chem.-Met. Eng. 342, Chem. 265, 266 or permission of instructor. (3).*
Principles of the kinetics of electrochemical processes, e.g. electroplating, fuel cells, batteries, chemical synthesis, etc. Two-thirds of the course is associated with the theory and applications of electrochemical kinetics found in the current literature; the remainder, with commercial applications of electrochemistry.

521. Petroleum Engineering. *Prerequisite: Chem.-Met. Eng. 343. (3).*
Properties of petroleum, process design in the production and refining of 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.

574. Metals at High Temperatures. *Prerequisite: Chem.-Met. Eng. 371, 470, or 479. (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. Phase Changes and Properties of Alloy Steels. *Prerequisite: Chem.-Met. Eng. 471 or equivalent. (3).*
Theory and practice of alloy additions to steel and the effect of alloying elements on properties of steels.

577. Metallurgical Operations. *Prerequisite: Chem.-Met. Eng. 489. (3).*
The plastic deformation of metals and alloys. Rolling, forging, extrusion, piercing, and deep drawing.

579. Nuclear Metallurgy. *Prerequisite: a course in physical metallurgy. (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.

581. Engineering Process Design. *Prerequisite: Chem.-Met. Eng. 481. (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. (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. (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.

584(Civ. Eng. 587) (Microb. 584). Industrial Microbiology. *Prerequisite: Chem.-Met. Eng. 434 (3).*
Lectures and demonstrations to illustrate the application of microbiological principles and techniques to industrial processes.

585. Petrochemical and Refining Studies. *(4).*
Designs and economic studies of selected petrochemical and refining processes.

586. Nuclear Fuels and Fuel Processing. *(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.

589. Cast Metals in Engineering Design. *Prerequisite: Chem.-Met. Eng. 470, 479, or permission of instructor. (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. (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. (3).*
Special subjects in chemical engineering fundamentals and applications. Intensive summaries of recent research.

645. Process Analysis. *Prerequisite: Chem.-Met. Eng. 400 or equivalent. (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. (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. (3).*
Consideration of statistical methods which are useful in designing and analyzing experiments involving several variables.

672. X-ray Diffraction II—Applications. *Prerequisite: Chem.-Met. Eng. 572 or permission of instructor. (3).*
Applications of advanced diffraction methods of importance in materials and metallurgical engineering. Fourier analysis of x-ray diffraction peak shapes, stacking fault and twin fault analysis, small angle and diffuse scattering measurements, and x-ray topography.

690. Research and Special Problems. *(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 term 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. (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.

801. Seminar in Chemical Engineering Analysis. *Prerequisite: Chem.-Met. Eng. 500. (3).*
Modern developments in the analysis and solution of chemical engineering problems.

830. Seminar in Engineering Thermodynamics. *Prerequisite: Chem.-Met. Eng. 530. (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. (3).*
Selected subjects in thermodynamics. Irreversible thermodyanmics, and statistical mechanics applied to metallurgical systems.

840. Heat Transfer Seminar. *Prerequisite: Chem.-Met. Eng. 541. (3).*
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. 542. (2).*

843. Seminar in Separation Processes. *Prerequisite: Chem.-Met. Eng. 543 or equivalent. (3).*
Individual study of advanced topics in the field of separation and purification processes. Seminar and reports.

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.

981. Professional Engineering Project. *(1).*
The engineering design and economic analysis of a process or research proposal. The project is to represent original, individual work; excellence of reporting is emphasized. If the project is conducted during a University recess, the course is to be elected in the term in which the report is started or submitted. Required of all applicants for the doctorate.

999. Doctoral Dissertation. *(To be arranged.)*

Chemistry*

Department Office: 2035 Chemistry Building
Professors Overberger and Taylor; Professors Anderson, Bartell, Brockway, Dunn, Elderfield, Elving, Halford, Nordman, Oncley, Parry, Rulfs, Smith, Stiles, Tamres, and Westrum; Associate Professors Blinder, Gordus, Lawton, Longone, H. B. Mark, and Martin; Assistant Professors Ashe, Brintzinger, Catherino, Current, Curtis, Ege, Gendell, Green, Griffin, Kopelman, Kuczkowski, Le Quesne, J. E. Mark, Rasmussen, Verdieck, and Wiseman.

Laboratory fees in the range from $12.50 to $30 must be paid in advance for each course involving laboratory work.

* College of Literature, Science, and the Arts.

103. General and Inorganic Chemistry. *Prerequisite: three years of high school mathematics.* I, II, *and* IIIa. *(4).*

Laboratory fee. Students continuing Chemistry after completing Chem. 103 are expected to elect Chem. 105 the following term since the two form a complete sequence which includes some organic chemistry. Three lectures, two recitations, and one two-hour laboratory period. A course intended for students who had limited earlier exposure to Chemistry.

104. General and Inorganic Chemistry. *Prerequisite: three years of high school mathematics and a strong background in high school chemistry validated by a satisfactory grade on the placement test given during the orientation period.* I. and II. *(4).*

Laboratory fee. Courses 104 and 106 form a one-year general chemistry sequence which has no organic chemistry. Three lectures, one recitation, and one three-hour laboratory period. This sequence is recommended for Chemical Engineers and other engineers whose curriculum demands a rather extensive training in Chemistry. A rather intensive development of chemical equilibrium is given.

105. General and Inorganic Chemistry. *Prerequisite: Chem. 103; (students having had Chem. 104 will need special permission).* I, II, and III *a. (4).*

Laboratory fee. A continuation of Chem. 103. Three lectures, two recitations, and one two-hour laboratory period. Not recommended as a prerequisite for chemistry courses numbered above 300 although permission may be granted in special cases.

106. General and Inorganic Chemistry. *Prerequisite: Chem. 104; Chem. 103 will be accepted only under special circumstances.* I and II. *(4).*

Laboratory fee. A continuation of Chem. 104. Three lectures, one recitation, and one three-hour laboratory period. A continuation of the discussion of chemical energetics, equilibrium electrochemistry, and related topics.

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 respectively.* I. *(5).*

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 (Honors). *Prerequisite: Chem. 103 or 104 with a grade of A or high B; Math. 115.* II. *(5).*

Laboratory fee. Three lecture-recitation periods and eight hours of laboratory work. Ionic equilibria, introduction to use of thermodynamic functions, and qualitative analysis of the metallic ions.

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).*

Laboratory fee. Chemical equilibria, electrochemistry, kinetics, atomic and nuclear structure, modern inorganic chemistry, properties of matter from the standpoint of atomic structure. Lectures, recitation, laboratory.

225. Organic Chemistry. *Prerequisite: Chem. 105, 106, 107, 191, or 195.* I, II, and III*a*. *(3).*
Chem. 225 and 226 constitute a year's course in lecture material in organic chemistry. Course 225 covers aliphatic compounds, carbohydrates, and other selected topics. Students should plan to elect courses 225 and 226 in consecutive terms.

226. Organic Chemistry. *Prerequisite: Chem. 225.* I, II, and III*a*. *(3).*
Aromatic compounds, proteins, and other topics.

227. Organic Chemistry. *Prerequisite: Chem. 225.* I and II. *(2).*
Designed to accompany Chem. 226. Basic laboratory procedures involved in the preparation of aliphatic and aromatic compounds.

228. Organic Chemistry. *Prerequisite: Chem. 226 and 227.* I and II. *(2).*
Continuation of the study of laboratory techniques involved in organic chemistry.

265. Principles of Physical Chemistry. *Prerequisite: Chem. 106 or 107 and preceded or accompanied by Math. 116 or 186 and Physics 145 or 153.* I and II. *(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.* II. *(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. 105, 106, 107, 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 and 468 or 265.* 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. 228 or 295.* I and II. *(3).*
Fundamental organic reactions are studied as a basis for systematic analysis and identification of organic compounds.

447. Physical Methods of Analysis. *Prerequisite: Chem. 346 and 468.* I and II. *(4).*
Theory, operation, and applicability of the principal physical and physiochemical approaches used in chemical analysis, including electrical, optical, and radio-chemical methods. Lecture, recitation, and laboratory.

468. Physical Chemistry. *Prerequisite: Physics 146, and Math. 214 or 215 and three terms of chemistry.* 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 and Math. 316.* 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, II, and III*a*. *(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, II, and III*a*. *(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 Macromolecules. *Prerequisite: Chem. 226 or 295.* II. *(2).*
The preparation, reactions, and properties of high molecular weight polymeric materials of both natural and synthetic origin.

555. Radioisotope Techniques. *Prerequisite: permission of instructor.* I. *(3)*
Elementary theory of nuclear transitions and of interactions of radiations with matter. Laboratory work (fee) deals with methods of production, manipulation, and detection of radioactive materials.

Civil Engineering

Department Office: 304 West Engineering

262. Geodetic Engineering I. *Prerequisite: Math. 116.* I. *(3).*
Basic principles of geodetic measurements as required on important engineering projects; use of theodolite, tilting level, and precise taping procedures; reduction of observations for calibration and observational procedures; simple positional computations and adjustments; topographic mapping; horizontal and vertical curves, and elementary earthwork computations. One lecture, two laboratory sessions per week.

263. Geodetic Engineering II. *Prerequisite: Math. 273, Civ. Eng. 262.* I and II. *(4).*
Principles of geodetic engineering computations; co-ordinates as a computational system; applications of electronic computers; concepts, requirements, and specifications for engineering positional control; least-squares adjustment; elementary photogrammetry; engineering astronomy; electronic distance-measurement; property surveys. Two lectures; two laboratory sessions per week.

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. *(2).*
Application of fundamental structural theory to design problems in which the properties of the material are important factors. Composition of members, connections, and arrangement of elements into structures are studied on a practical basis.

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.

363. Basic Surveying. *Prerequisite: Math. 115 or equivalent.* I. *(2).*
For non-civil 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.* I. *(3).*
Similar to Civ. Eng. 262. Designed for forestry students.

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 and II. *(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 I. *Prerequisite: preceded or accompanied by Eng. Mech. 324 or permission of instructor.* I and II. *(2).*
The hydrologic cycle and the runoff process; precipitation, its causes, variability, distribution, and frequency; snow melting processes; evaporation, transpiration and other water losses; infiltration; ground water occurrence and movement; normal and low flows; magnitude and frequency of floods; flood routing; selection of storage requirements for water supplies; method of measuring river discharge.

421. Hydraulics. *Prerequisite: Eng. Mech. 324, Math. 273.* 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, preceded or accompanied by Eng. Mech. 324 and Chem.-Met. Eng. 250.* I and II. *(3).*
Soil classification and index properties; soil structure and moisture, seepage; compressibility and consolidation; stress and settlement analysis; shear strength. Lectures, problems, and laboratory.

470. Transportation Engineering. *Prerequisite: Civ. Eng. 263 and preceded or accompanied by Eng. Mech. 343 and Civ. Eng. 445.* I and II. *(3).*
Planning, location, design, and operation of transportation facilities. Introduction to engineering economics.

471. Traffic Engineering. *Prerequisite: Civ. Eng. 470 or permission of instructor.* II. *(3).*
Driver-vehicle road operating characteristics and studies, traffic planning, geometric design, and control.

473. Highway Design. *Prerequisite: Civ. Eng. 470.* I. *(3).*
Studies of highway alignment, profiles, and intersections.

474. Railroad Engineering. *Prerequisite: Civ. Eng. 470.* II. *(3)*
The planning, location, design, construction, and operation of railroad facilities.

480. Water Supply and Treatment. *Prerequisite: Junior or Senior standing.* 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. *Prereqisite: Eng. Mech. 324 or permission of instructor.* III*a*. *(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.* III*b*. *(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. II. *(3).*
Duty of care, labor law including the related Acts of Congress, social security, unemployment compensation, industrial injuries. Cases, lectures, and discussion.

505. Boundary Surveys. *Prerequisite: Civ. Eng. 262 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.

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 Metal Structures. *Prerequisite: Civ. Eng. 313 and 415.* I and III*a*. *(3).*
Structural design problems and reports. Introduction to plastic design and composite design. Modern trends in bridge and building construction. Industrial buildings. Comprehensive design project.

514. Rigid Frame Structures. *Prerequisite: Civ. Eng. 313 and 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.* II. *(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 473.* 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.

518. Design in Reinforced Concrete. *Prerequisite: Civ. Eng. 415 and preceded or accompanied by Civil Eng. 514.* I. *(2).*
Design of reinforced concrete structural systems using both working stress and ultimate strength design methods.

519. Plastic Analysis and Design of Frames. II. *(3).*
Plastic analysis of structural frames. Rules of practice for the plastic design of steel structures. Design problems and reports.

520. Hydrology II. *Prerequisite: Civ. Eng. 420 and 421 or equivalent.* II. *(2).*
Factors affecting runoff; methods of predicting runoff from rainfall; variation of infiltration capacity and surface runoff parameters with seasonal factors and characteristics of the drainage basin, urban runoff; characteristics of aquifiers; ground water and well hydraulics.

523. Flow in Open Channels. *Prerequisite: Civ. Eng. 421 or equivalent.* I and II. *(3).*
Energy and momentum concepts; flow in the laminar and transition ranges; selection of canal cross-sections; minor losses; critical depth; rapidly varied flow; controls; gradually varied flow; channels of varying width; steep chutes; translatory waves; high velocity transitions; bends. Lectures and demonstrations.

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. Design of Hydraulic Systems. *Prerequisite: Civ. Eng. 415 and 420; preceded or accompanied by Civ. Eng. 523.* II. *(3).*
Hydraulic aspects of the design of canals, dams, gates, spillways, sea walls, breakwaters and other structures. Determination of the most economic design of an hydraulic engineering project. Application of the digital computer to engineering design.

529. Hydraulic Transients I. *Prerequisite: Civ. Eng. 421 or permission of instructor.* I. *(3).*
Incompressible unsteady flow through conduits; numerical, algebraic and graphical analysis of waterhammer; solution of transient problems by the method of characteristics; digital computer applications to pump failures, complex piping systems, valve stroking, and liquid column separation.

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.

534. Construction Methods and Equipment. *(2).*
Open to seniors and graduates. Contractors' organizations; 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. 470 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 Civil Engineering Systems. I and II. *(3).*
Open to senior and graduate students. Critical path planning and scheduling, CPM and PERT programs, manpower and equipment leveling, minimum cost expediting.

542. Physico-Chemical Principles in Soil Engineering. *Prerequisite: Civ. Eng. 445, Chem. 265, or permission of instructor.* II. *(2).*
Soil formation, clay mineralogy, colloidal phenomena in soils, determination of soil minerals, relationships between soil composition and behavior, soil structure and its significance in determining soil properties and in engineering problems, time-deformation processes in soils, volume changes in clay soils, soil stabilization.

543. Soils in Highway and Airport Engineering. *Prerequisite: Civ. Eng. 445 and 470.* I. *(3).*
Soil engineering as applied to highways and airports; soil and material surveys, soil classification, subgrades, drainage, frost action and soil stabilization; embankment construction; airphoto analysis.

545. Foundations and Underground Construction. *Prerequisite: Civ. Eng. 445.* I. *(3).*
Soil as an engineering material, measurement of soil resistance in the field and laboratory; bearing capacity for spread footings and mats; friction piles, group capacity, bearing piles and caissons in deep foundations, mass stability, storage capacity, excavations, and large caissons; earth pressure, retaining walls, and tunnels; subsidence and control of damage from subsurface excavation. Lectures, references, and design problems.

546. Soil Mechanics Laboratory. *Prerequisite: a course in soil mechanics.* 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.

547. Principles of Pavement Design. *Prerequisite: Civ. Eng. 445 and 470.* II. *(3).*
Design of pavements for highways and airports; stresses in pavements; properties of pavement components; design of rigid and flexible pavements; pavement evaluation and strengthening.

548. Marine Structures and Foundations. *Prerequisite: Civ. Eng. 445 or permission of instructor.* II. *(3).*
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.

549. Case Studies in Soil Mechanics Practice. *Prerequisite: Civ. Eng. 445.* I and II. *(2).*
Review of selected projects in which soil mechanics played a major role; presentation in chronological sequence of soil investigation, design, construction control, contract administration, claims and litigation. Lectures and seminar.

550. Highway Materials. *Prerequisite: preceded or accompanied by Civ. Eng. 470.* I. *(3).*
Sources, production, and testing of highway materials; specifications; minor research problems.

552. Bituminous Materials and Pavements I. *Prerequisite: Civ. Eng. 470.* II. *(3).*
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. 263.* 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).*
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. 316 and Civ. Eng. 263, or permission of instructor.* I and II. *(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. Problems in Geodetic Engineering. *Prerequisite: permission of instructor.* I and II. *(To be arranged).*
Advanced problems in geodetic engineering.

565. Municipal Surveying. *Prerequisite: Civ. Eng. 263.* I. *(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. Urban Traffic. *Prerequisite: senior or graduate standing.* I and III*b*. *(2).*
Urban traffic determinants. Planning, design, and operation of urban transportation facilities. Not open to engineering students.

572. Highway Economics, Finance, and Administration. *Prerequisite: Civ. Eng. 470.* I and III*a*. *(3).*
Application of principles of engineering economics to highway planning, location, and design. Methods of financing highway facilities. The administration of public transportation agencies.

577. Traffic Flow I. *Prerequisite: a course in statistics.* I. *(3).*
Studies of determinants and characteristics of traffic flow and accidents.

580(Chem.-Met. Eng. 434) (Microb. 434). Microbiology I. *Prerequisite: Math. 316, Chem. 225, and senior standing, or permission of instructor.* I. *(3).*
Principles and techniques of microbiology with an introduction to their application in the several fields of engineering. Lectures and laboratory.

581. Applied Chemistry of Water and Waste Water. *Prerequisite: Chem. 106 or equivalent.* I. *(3).*
Principles and application of the chemistry of aqueous systems; homogeneous and heterogeneous equilibria of chemical systems of import in natural waters and waste waters, and in the treatment thereof; principles and techniques of analytical methods for evaluating the quality of waters and waste waters. Two lecture periods and one laboratory session per week.

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 foı 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. Solid Wastes Engineering. *Prerequisite: permission of instructor.* II. *(3).*
The engineering and design of methods for the collection and disposal of the solid wastes of urban communities and the related effects of such collection and disposal on the environment.

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(Chem.-Met. Eng. 584) (Microb. 584). 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.

588. Water Resource Systems and Economics. *Prerequisite: Math. 465 or permission of instructor.* I. *(3).*
Introduction to systems analysis and related topics in the field of water resources. Uses of mathematical programming techniques in water resources decision problems. Cost benefit analysis and its application to contemporary water resource projects and resource economics and its implications for water quality problems.

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).*
Elastic and inelastic behavior of beams and columns. Torsion of solid and box members. Combined bending and torsion. Buckling of beams and beam columns.

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. 512 and 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.

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 and Math. 273, or equivalent.* 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.

622. Special Problems in Hydraulic Engineering or Hydrology. *Prerequisite: permission of instructor.* I and II. *(To be arranged).*
Assigned work on an individual basis. Problems of an advanced nature may be selected from a wide variety of topics.

623. Coastal Hydraulics. *Prerequisite: Civ. Eng. 523.* II. *(2).*
Equations of oscillatory wave motion; generation of waves by wind; refraction; energy transmission, breaking waves, diffraction; energy dissipation; run-up and overlapping; wave forces; currents and wind tides; shore erosion processes; harbor design.

624. **Free Surface Flow.** *Prerequisite: Civ. Eng. 523 or permission of instructor.* II. *(2).*
Dynamics of spatially varied flow; unsteady momentum and continuity equations applied to prismatic and nonprismatic channels. Rainfall and overland flow relationships; flood routing in channels subject to material inflows. Unsteady free surface flow in porous media. Simulation techniques using the digital computer.

629. **Hydraulic Transients II.** *Prerequisite: Civ. Eng. 529 or permission of instructor.* II. *(3).*
Steady-oscillatory flow by impedance methods and characteristics methods; self-excited and forced resonance of piping systems; pulsatile flow through distensible tubes. Digital computer applications to reciprocating pumps, valving, resonance in complex piping systems, hydropower system governing flow through arteries.

644. **Airport Planning and Design.** *Prerequisite: Civ. Eng. 470 or permission of instructor.* III*a*. *(3).*
Planning, site selection and configuration; airport capacities; air traffic control; geometric design of landing area; development of terminal area; lighting; pavement requirements; drainage.

645. **Theoretical Soil Mechanics I.** *Prerequisite: permission of instructor.* I. *(3).*
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. *(3).*
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. **Advanced Soil Mechanics Laboratory.** *Prerequisite: preceded or accompanied by Civ. Eng. 648. (1).*
Triaxial testing of soils under static conditions; field and laboratory determination of dynamic soil properties; vibration measurements.

648. **Dynamics of Soils and Foundations.** *Prerequisite: Civ. Eng. 445 or equivalent. (3).*
Transient and steady state vibrations of foundations; phase plane analysis of foundations with one and two degrees of freedom; dynamic properties of soils; vibration transmission through soils.

652. **Bituminous Materials and Pavements II.** *Prerequisite: Civ. Eng. 552.* I and II. *(To be arranged).*
Conferences and special problems on new developments in bituminous materials and bituminous mixture design. Conferences, assigned reading, laboratory investigation, and reports.

670. **Transportation Planning.** *Prerequisite: Civ. Eng. 577 or permission of instructor.* II. *(3).*
Planning transportation facilities. Studies and analytical techniques used in estimating transportation demand. Evaluating alternative transportation systems.

671. **Highway Engineering Seminar.** *Prerequisite: Civ. Eng. 470 or permission of instructor.* I and II. *(2).*
Seminar 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.

675. Geometric Design of Highways and Interchanges. *Prerequisite: Civ. Eng. 577 or permission of instructor.* II. *(3).*

676. Traffic Control. *Prerequisite: Civ. Eng. 577.* II. *(3).*
Theory and application of traffic control techniques.

677. Traffic Flow II. *Prerequisite: Civ. Eng. 676.* I and III*a*. *(3).*
Detailed studies of microscopic and macroscopic traffic flow theories.

678. Transportation and Traffic Engineering Seminar. I and II. *(1).*
Lectures, assigned reading, and student reports on problems selected from the fields of transportation and traffic engineering.

680. Microbiology II. *Prerequisite: Civ. Eng. 580 or equivalent.* II. *(2).*
Lectures and laboratory dealing with inter-relationships between organisms of sanitary significance such as fungi, algae, protozoa, and higher forms of invertebrates.

681. Chemical Kinetics and Thermodynamics in Aqueous Systems. *Prerequisite: Civ. Eng. 581.* II. *(3).*
Energetics and kinetics of chemical and biochemical reactions of significance in natural waters and in processes used for treatment of waters and waste waters; mass transfer and transport phenomena in natural aqueous systems and in chemical and biological treatment processes.

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. Designed to broaden the graduate student's perspective in one or more special fields.

686. Special Problems in Sanitary Engineering II. *(To be arranged).*
Advanced problems in specialized areas of sanitary engineering.

687(E.H. 687). Special Problems in Solid Wastes Engineering. *Prerequisite: Civ. Eng. 585 and permission of instructor.* I, II, III*a* and III*b*. *(To be arranged).*
Application of principles presented in Civ. Eng. 585 to engineering and environmental health problems in the collection and disposal of solid wastes; comprehensive analysis and report assigned on an individual student basis.

688. Operations Research in Environmental and Water Resources Engineering. *Prerequisite: Ind. Eng. 472 or permission of instructor.* II. *(3).*
Applications of operations research techniques in environmental and water resources engineering; mathematical programming and optimization procedures, stochastic description of environmental systems, queueing and inventory models; decision theory approach to environmental and water resources problems.

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.

781. Colloidal and Interfacial Phenomena in Aqueous Systems. *Prerequisite: Civ. Eng. 681 or permission of instructor.* II. *(3).*
The behavior of surfaces and interfaces in aqueous systems, with particular emphasis on liquid-solid interfaces, sorption and exchange reactions, particle growth kinetics, and coagllation phenomena; also detailed consideration of the chemistry of metal ions in aqueous solution, including coordination, complexometric, and polymerization reactions.

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.

881. Water Resources Research Seminar. *Prerequisite: advanced graduate standing.* I and II. *(1).*
Presentation and discussion of selected research topics relating to physical, chemical, and biological aspects of water resources and to the design of water resources systems. Student participation and guest lecturers.

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).*
Individual or group research in particular topics in hydrology. A variety of topics may be selected.

921. Hydraulic Engineering Research. *Prerequisite: permission of instructor. (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, experiments in the laboratory, searches in the library and among public records, and drafting room designing.

999. Doctoral Thesis. I, II, III, III*a* and III*b*. *(To be arranged).*
For doctoral candidates only, under supervision of the individual's doctoral committee.

Communication Sciences*

Department Office: 3057 Administration Building

Professors Burks, Chairman, Galler, Garner, Hok, Holland, Melton, Rapoport and Swain; Associate Professors Arden, Lawler and Pew; Assistant Professors Flanigan, Meyer, Rosenberg; Lecturers O'Malley, Peck and Reiter; Visiting Professor Muller.
The following courses have been developed through the co-operation of the College of Engineering, the Medical School, and the College of Literature, Science, and the Arts.

200. Introduction to the Communication Sciences. *Prerequisite: one year of college mathematics or science.* II. *(3).*
Computer organization, the nature of theory, comparison of natural and artificial languages, automata theory, discrete information theory, information processing aspects of natural systems. (Not open to students eligible for Com. Sci. 400.)

274. Elementary Computer Methods. *(2).*
Introduction to elementary programming ideas and languages. Examples will be drawn from elementary statistical and experimental situations. (Not open to students eligible for Math. 273.)

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. Communication 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.

430. Communications Electronics II. *Prerequisite: Com. Sci. 410 or Elec. Eng. 330. (3).*
Wide-band amplifiers; radio-frequency amp.; modulation/detection; transmitting and receiving circuits; radio-frequency transmission lines.

441. Phonetic Theory. *Prerequisite: Com. Sci. 200 or 400 or Ling. 411 (may be taken concurrently), or permission of instructor.* I. *(3).*
A study of the physiological and acoustical basis of descriptive phonetics. Phonetic systems and problems in phonetic theory will be considered in detail.

* College of Literature, Science, and the Arts.

473(Math. 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.

475. Digital Computers and Computation. *Prerequisite: Com. Sci. 400 (possibly concurrent), college calculus, Com. Sci. 274 or equivalent. (3).*
The course covers the organization of digital computing machines, selected algorithms, and programming languages.

500. Special Study. *Prerequisite: permission of instructor. (1-6).*
Special reading and study in particular areas of communication sciences for advanced undergraduates and beginning graduates.

510. Signal Theory. *Prerequisite: Com. Sci. 410 or Elec. Eng. 330, and Com. Sci. 530.* 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 or Philos. 414, or Math. 481, or permission of instructor.* II. *(3).*
Application of logic to finite computers, Turing machines, probabilistic automata, and self-reproducing systems.

524. Adaptive Systems. *Prerequisite: Com. Sci. 400 or 522 or Elec. Eng. 465, or permission of instructor.* II. *(3).*
The organization, design, and programming of automata which change their structure and behavior in order to adapt to environments containing them.

530. Introduction to Stochastic Processes and Information Theory. *Prerequisite: Com. Sci. 400 (may be taken concurrently) and Math. 425.* I. *(3).*
Introduction to stochastic processes and information theory with applications to the communication sciences. Topics studied include random variables, sample spaces, measures and distributions, conditional probabilities, Bayes' theorem, sampling theorems, coding theorems, and capacity theorems.

540. Language and Behavior. *Prerequisite: Psych. 443 or Com. Sci. 400 or permission of instructor. (3).*
The methods of structural linguistics and experimental psychology are jointly applied to the study of language as a form of behavior.

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.

542. Mathematical Linguistics. *Prerequisite: Com. Sci. 400, and Math. 425 or 465.* II. *(3).*
The statistical properties of linguistic units; lexicostatistics. Finite-state and nonfinite-state languages. Algebraic models of natural languages.

544. Formal Structures of Individual Languages. *Prerequisite: Com. Sci. 541 (3).*
The detailed analysis of the systematic properties of a special language, including its phonology, morphology, and syntax.

546. Experimental Studies in Phonology. *Prerequisite: Engl. 414 or Com. Sci. 541, or permission of instructor.* I. *(3).*
The application of instrumental and experimental techniques to the study of the linguistic structure of speech. The relation between phonological units and experimental measurements. Lecture and laboratory.

550. Informational Processes in Behavioral Systems. *Prerequisite: Com. Sci. 400, or permission of the instructor.* I. *(3).*
A survey of behavioral concepts and principles, with special emphasis on those relevant to adaptive systems.

560. Theory of Coding I. *Prerequisite: Math. 425.* I. *(3).*
Coding theory as derived from probabilistic considerations. Introduction to information theory. Classifications of codes; Kraft condition codes, Shannon, Huffman, and Gilbert-More alphabetic codes. The Chernoff and Sterling approximation techniques, average upper and lower performance bounds for random, group, and convolution codes. Properties of simplex, orthogonal, and biorthogonal codes.

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 executive systems, list storage, threaded lists, and automatic programming languages.

580. Informational Aspects of Biochemistry and Physiology. *Prerequisite: Com. Sci. 400.* II. *(3).*
A survey of the role of information and control processes in biochemical and physiological systems.

582. Biological Sensory Systems. *Prerequisite: Com. Sci. 580 (may be taken concurrently), or permission of instructor.* II. *(3).*
Information processing in biological sensory systems, especially the eye and the ear. Perception, encoding, and transmission by the end organs. Analysis of sensory inputs by the central nervous systems.

622. Algebraic Theory of Automata. *Prerequisite: Com. Sci. 522, or Elec. Eng. 467, and Math. 517, or permission of instructor.* II. *(3).*
The emphasis is placed on the use of algebraic techniques in the study of the relation between structure and behavior. Material covered will include decomposition of sequential machines, probabilistic automata, and various special automata. The course will also treat certain topics such as the relation of automata theory to coding theory and to mathematical linguistics.

624. Theory of Adaptive Systems. *Prerequisite: Com. Sci. 524, or permission of instructor.* I. *(3).*
Presents a unified theory of the adaptive systems discussed in Communication Sciences 524.

630. Information Theory. *Prerequisite: Com. Sci. 530, and Math. 425 or 465.* I. *(3).*
The theory of selective information is developed from a formal mathematical point of view. The axiomatics and basic concepts of information theory are presented. The connection between information and physical entrophy is traced and applications of information theoretical ideas to biology and psychology are reviewed.

640. Neural Simulation and Psychological Processes. *Prerequisite: permission of instructor.* *(3).*
A consideration of neural simulation, with particular emphasis on neural models

of perceptual and cognitive processes. Mechanisms for preservation such as recycling and reverberation will be examined. The relevance of these models to various psychological phenomena, particularly those reflecting satiation or inaccessibility. Factors which could modulate perservative activity, emphasis on potential individual difference dimensions.

642. Semantic Theory. *Prerequisite: Com. Sci. 541, or permission of instructor.* I. *(3).*
The extension of mathematical theories of grammar to semantics.

644. Theories of Grammar. *Prerequisite: Com. Sci. 541.* I. *(3).*
A study of major theories of grammar of natural language.

646. Acoustical Theory of Speech Communication. *Prerequisite: Com. Sci. 546. (3).*
An analysis of the research literature on the acoustical theory of speech. The study of instrumental and experimental techniques in speech analysis. Lecture and laboratory.

648. Automation of Natural Languages. *Prerequisite: Com. Sci. 541. (3).*
Automatic speech recognition, speech synthesis, and the machine translation of languages. The basic theoretical problems involved, current research literature, and current instrumental techniques in the field are studied.

660. Algebraic Coding Theory II. *Prerequisite: Math. 513 or 517.* II. *(3).*
Continuation of Com. Sci. 560.

680. Simulation of Biological Systems. *Prerequisite: Com. Sci. 410, 473 or 475, 580, or permission of instructor. (3).*
Investigation of techniques used in the simulation and modeling of biological systems.

801. Seminar in Communication Sciences. *Prerequisite: permission of instructor. (To be arranged).*

802. Seminar in Communication Sciences. *Prerequisite: permission of instructor.* I. *(3).*

803. Seminar in Communication Sciences. *Prerequisite: Com. Sci. 802. (3).*
Continuation of Com. Sci. 802.

804. Seminar in Automata Theory. *Prerequisite: Com. Sci. 522 or permission of instructor.* 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*

Department Office: 105 Economics Building

Professor Brazer, Chairman; Professor Palmer, Associate Chairman; Professors W. H. L. Anderson, Bornstein, Boulding, Brazer, A. Eckstein, Ford, Fusfeld, Haber, Katona, Lansing, Levinson, Morgan, Mueller, Palmer, Porter, Smith, Steiner, Stern, Stolper, Suits, Winter, Yudelman; Associate Professors G. Anderson, Barlow, Cross, Demeny, Dernberger, Hymans, Feldstein, Newell, Mooney,

* College of Literature, Science, and the Arts.

Scherer, Shapiro, Shepherd, Strumpel, Taylor, Teigen; Assistant Professors P. Eckstein, Holbrook, Johnson, Klass, Manore, Munk, Neenan, Yoshihara; Lecturers Crafton, Freedman, Shulman.

A. Introductory Courses

201, 202. Principles of Economics. *Prerequisite: Econ. 201 is a prerequisite to Econ. 202 and both are prerequisite to the more advanced courses in the department. Open to freshmen in College Honors Program and to other freshmen with special permission.* 201, I and II.; 202, I and II. *(4 each).*
The basic ideas of economics—related to production and national income, business organization, money and banking, depressions and employment, markets, prices, competition and monopoly, distribution of income, government finance, and international dealings—are developed carefully and applied to leading problems of broad public interest.

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. *(4).*
For juniors, seniors, and graduates who have had no course in economics and who desire one term 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.

B. Advanced Courses

411, 412. Money and Banking. *Prerequisite: Econ. 201 and 202. Econ. 411 is prerequisite to Econ. 412.* 411, I; 412, II. *(3 each).*
Nature and function of money and banking and contemporary monetary problems.

421, 422. Labor. *Prerequisite: Econ. 201 and 202.* 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.

433. Transportation. *Prerequisite: Econ. 201 and 202.* II. *(3).*
An economic analysis of the transportation industries and the application of this analysis to public policy problems.

434. Public Utilities. *Prerequisite: Econ. 201 and 202.* II. *(3).*
Nature and problems of the public utility industries from the standpoint of government regulation.

457. Comparative Economic Systems. *Prerequisite: Econ. 201 and 202.* I and II. *(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.

475. Economic Statistics. *Prerequisite: Econ. 201 and 202.* I and II. *(3).*
Introduction to the principal methods of statistical analysis as applied to economic problems.

481. Public Finance. *Prerequisite: Econ. 201 and 202.* I. *(3).*
Principles and problems of government finance—federal, state, and local.

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.

Electrical Engineering

Department Office: 2500 East Engineering

210. Circuits I. *Prerequisite: Math. 215 and Physics 146. (4).*
Models of circuit elements; Kirchhoff's laws and equilibrium equation formulation. Network theorems and graphical analysis. Exponential and singularity functions. Solution of equilibrium equations; superposition; natural and particular responses. Analogs, system functions, poles and zeros. Frequency response curves, resonance, phasor diagrams, and use of pole-zero plots. Three lectures and one three-hour computing period.

215. Network Analysis. *Prerequisite: preceded or accompanied by Math. 216. (3).*
Analysis of linear circuits containing resistive, inductive and capacitive elements and voltage and current sources. Complete solution for general time-variable sources, including transient, periodic and steady state responses. Phasor and transform analysis techniques. Mesh, nodal, and ladder analysis; network functions; Thevenin's and Norton's theorems; power and energy balance. Coupled circuits and transformers; two-port theory.

220. Electromagnetic Field Theory I. *Prerequisite: Physics 146 and preceded or accompanied by Math. 316. (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 communications 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 and preceded or accompanied by Math. 316. (4).*
Time and frequency domain interrelations. Topology, selection of variables, loop, node-pair, and state-variable approaches. Natural frequencies, dual systems, 2-port representation. Transformers, power, impedance matching, frequency response, three phase systems. Fourier series, complex variables, Fourier and Laplace transforms. Transmission lines. Lectures and laboratory.

314. Circuit Analysis and Electronics. *Prerequisite: Math. 316 and Physics 146. (3).*
A comprehensive treatment of passive and active (electronic) circuit theory expressly developed to satisfy the requirements of non-electrical engineering students. Formulation of circuit equations; node and loop methods; steady-state and transient response of RL and RC circuits, two-port networks; analysis of

basic electronic circuits. Not open to electrical engineering or science engineering students.

315. Circuit Analysis and Electronics Laboratory. *Prerequisite: preceded or accompanied by Elec. Eng. 314. (1).*
Laboratory lecture demonstrations and student experiments designed to investigate the principles developed in Elec. Eng. 314. Measurements of voltage, current, resistance, power, transient response, transistor characteristic, and amplifier preformance. Lecture-demonstration and two-hour laboratory. Not open to electrical engineering or science engineering students.

320. Electromagnetics. *Prerequisite: preceded by Elec. Eng. 215, Physics 154, and Math. 216. (4).*
Analysis of phenomena depending upon electrical charge and current in terms of the field concept. Fields due to distributions of electrical charges and currents; introduction to electric and magnetic properties of materials; capacitance and inductance of configurations of conductors; electrical conduction and resistance; semi-conductors; ferro-magnetism; magnetic circuits; electromagnetic induction; Maxwell's equations; plane electromagnetic waves. Three lectures and one three-hour laboratory.

330. Electronics and Communications I. *Prerequisite: Elec. Eng. 310 and 381 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. Introduction to Lagrange's equations, Hamiltonian functions, and Legendre transformations. Applications to elementary electromechanical, hydraulic, photo-electric, thermalelectric 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.

380. Principles of Physical Electronics. *Prerequisite: Elec. Eng. 210 or 314 and 315, 220, preceded or accompanied by Mech. Eng. 331. (3).*
Electron ballistics; physical principles of vacuum tubes; quantum concepts; energy levels in atoms; electronic phenomena in metals; thermionic emission; gaseous conduction phenomena; gas tubes; physical properties of semiconductors; junction theory and applications; transistor properties and characteristics. Lectures.

381. Physical Electronics Laboratory. *Prerequisite: preceded or accompanied by Elec. Eng. 380 or 383. (1).*
Measurement of electron trajectories in electric and magnetic fields; electron beam focusing; thermionic and photoemission; vacuum tube characteristics;

plasma characteristics; conductivity, mobility, lifetime and diffusion in semiconductors; junction characteristics; transistor characteristics. One lecture and one three-hour laboratory.

383. Physical Electronics I. *Prerequisite: Elec. Eng. 210 or 314 and 315, 220, preceded or accompanied by Mech. Eng. 331. (3).*
Electrical conduction in vacuum and gas; motion of single charged particles, collective motion of charged particles, statistical description of charged particle motion; introductory quantum concepts; applications to electron-optical devices, space-charge control devices, electron beams, microwave tubes electron emission, gaseous conduction devices.

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-parameter 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. 314 and 315 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.

421. Electromagnetic Field Theory Laboratory. *Prerequisite: preceded or accompanied by Elec. Eng. 420. (1).*
Laboratory course with experiments chosen from a list designed to emphasize properties and the nature of electromagnetic fields and distributed-parameter systems.

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.

438. Electronics and Radio Communications. *Prerequisite: Elec. Eng. 310 or 314 and 315 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.

442. Analysis of Electromechanical Devices. *Prerequisite: Elec. Eng. 314 and 315. (4).*
Three-phase circuits; Laplace transforms and transient response, magnetic circuits and energy balance; electromechanical energy conversion, direct-current and alternating-current machine applications; automation; electrical transducers; 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).*
Utilization of Lagrange's equations, Legendre transformations, and energy conversion principles in a unified and integrated treatment of transformers, d-c and a-c machines, direct energy converters. Introduction to feedback control system concepts including stability, transfer functions, frequency response functions and state variables. Lectures and laboratory.

445. Theory of Linear Systems and Introduction to Control Systems. *Prerequisite: Elec. Eng. 310 or permission of instructor. (3).*
An advanced treatment of transform methods of solution for transients in time invariant linear systems; introduction to the complex frequency domain, a theoretical study of feedback control systems; transfer function analysis; stability considerations; system sensitivities; root locus and frequency response techniques.

446. Control Systems Engineering Computing Laboratory. *Prerequisite: Elec. Eng. 445 or Info. and Cont. Eng. 570 or permission of instructor. (1).*
Project laboratory experiments on typical elementary control systems; control system design.

465. Electronic Computers I. *Prerequisite: Math. 404 or 450, 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 a small hybrid computer and digital circuit modules to investigate circuits for arithmetic, control, and storage. Lecture and laboratory.

467. Switching Circuits and Finite State Systems. *Prerequisite: Elec. Eng. 465 or Math. 450 or permission of instructor.* I and II. *(3).*
Introduction to switching and automata theory. Essential concepts of lattice theory, Boolean algebra, graph theory. Application to analysis and design of switching circuits with emphasis on sequential circuits and other types of finite state systems.

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. (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. Coherent Optical Technology. *Prerequisite: preceded or accompanied by Math. 450 or permission of instructor. (3).*
Fourier-transform relationships in optical systems and various optical data-processing techniques for producing complex spatial filters; pattern recognition, multichannel cross-correlating spectrum analyzers, and other applications; electrical-to-optical transducers, recording media; ultrasonic cells and KDP modulators; holography with emphasis on the following aspects: magnification and aberrations, holographic interferometry vibration and stress analysis, holographic contouring, and holography using incoherent light.

476. Noncoherent Optical Technology. *Prerequisite: Math. 450 and preceded or accompanied by Physics 402, or permission of instructor. (3).*
Theory and instrumentation for sensing and measuring light and infrared radiation; topics include blackbody radiation (Kirchhoff's and Stefan's laws), refection and emission, detectors such as the eye, photon detectors, thermal detectors, and the photographic process; imaging detectors such as the image orthicon, vidicon, scanners, and image intensifiers; effects of noise; demonstrations with radiometric and spectrometric equipment.

480. Microwave and Quantum Electronic Devices. *Prerequisite: Elec. Eng. 380, 410, or 420. (3).*
Transit time effects: induced currents; velocity modulation and electron bunching theory; space-charge waves on electron beams; slow-waves on propagating circuits; introduction to coupled modes; space-charge and circuit wave coupling; application to microwave amplifiers and oscillators; parametric interactions; harmonic generation; and maser principle; energy level population distribution and inversion; solid state and gaseous lasers. Lectures and demonstrations.

481. Integrated Circuits. *Prerequisite: Elec. Eng. 330 or permission of instructor. (3).*
Monolithic, hybrid, and thin film electronic circuit technology, design, and performance; measurement and evaluation of representative circuit performance; correlation with physical and constructional parameters. Two lectures and one laboratory period.

483. Physical Electronics II. *Prerequisite: Elec. Eng. 380 or 383. (3).*
Introduction to quantum theory; Schroedinger equation and eigenstates; atoms, molecules, and crystalline solids; metals, insulators, and semiconductors; transport processes; p-n junction phenomena and devices; quantum devices; origin of magnetic properties of matter.

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 graduate students.

515. Network Synthesis I. *Prerequisite: Elec. Eng. 415 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.

528. Antenna Theory I. *Prerequisite: Elec. Eng. 420. (3).*
Integration of Maxwell equations; nature of far-zone fields; pattern and directivity; linear arrays, optimum directivity with or without constraints; impedance of cylindrical and biconical antennas; Rayleigh-Carson reciprocal theorem; receiving aperture for elliptically polarized waves; Friis transmission formula.

530. Microwaves I. *Prerequisite: Elec. Eng. 420. (3).*
General theory of waveguides and cavities; propagation in waveguides containing inhomogeneous and anisotropic media; surface waves; representation and analysis of microwave circuits and components including directional couplers, filters, ferrite isolators and circulators; variational techniques.

531. Electromagnetic Wave Propagation. *Prerequisite: Elec. Eng. 410; Elec. Eng. 420; Math. 450. (3).*
Radio propagation theory; antennas as wave launching devices; transmission loss; coherence factor; effects of lossy ground; ground-wave propagation, direct ground-reflected and surface waves; the ionosphere as a plasma, ionospheric propagation, maximum usable frequencies and absorption; sky-wave propagation; tropospheric propagation; ionospheric, tropospheric and meteor scatter; relay communication.

532. Digital Communications. *Prerequisite: Elec. Eng. 430. (3).*
Role of statistical decision theory in digital signalling; maximum likelihood reception, correlation detection. Digital methods: on-off keying, phase shift keying, binary orthogonal signals including pseudo-random sequences. Probability of error versus signal to noise ratio for above. Sampling of analog signals: PCM, delta modulation, external sampling, data omission. Synchronization, error coding, feedback communications.

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. (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 synchroton 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. (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.

537. Microwave Measurements. *Prerequisite: preceded or accompanied by Elec. Eng. 480 or 530. (2).*
Measurement of wavelength, impedance, and power; characteristics of microwave generators, amplifiers, detectors, and various microwave components; theory and use of spectrum analyzers. Lecture and laboratory.

539. Electronic Circuit Design. *Prerequisite: Math. 404 or 450, Elec. Eng. 330, or permission of the instructor. (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 nonsalient and salient pole machines. Direct and quadrature reactances under steady-state and transient conditions.

546. Digital Techniques in Control Systems. *Prerequisite: Elec. Eng. 445 or Info. and Cont. Eng. 570. (2).*
Introduction to discrete data systems and the use of digital computers in control systems; analysis of discrete systems using both classical and state space concepts; synthesis of control elements; digital filters; on-line use of digital computers in these systems.

547. Synthesis Problems in Control Systems Engineering. *Prerequisite: Elec. Eng. 445 or Info. and Cont. Eng. 570, or permission of instructor. (3).*
A detailed study of typical complex control systems, utilizing linear control theory; major component choices, performance criteria, system compensation; examples taken from aero space systems, machine tool control systems, process control systems. Inspection trips planned to neighboring industries to inspect systems studied in class.

549. Foundations of Control Systems Engineering. *Prerequisite: Elec. Eng. 445, or Info. and Cont. Eng. 570, or permission of instructor. (3).*
An introduction to the analysis of dynamic control systems utilizing the concepts of sets, function spaces, and linear operators to analyze continuous, dis-

crete, 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 Transmission Lines and Load Flow. *Prerequisite: Elec. Eng. 410. (3).*
Symmetrical components; representation of power systems; resistance, inductance, and capacitance of transmission lines. Current and voltage relations of transmission lines; network equations and solutions; load flow studies. Solution of problems on transmission line inductance and on load flow on the analog and the digital computer.

554. Load Flow and Economic Operation of Power Systems. *Prerequisite: Elec. Eng. 410. (3).*
Load flow studies; skin effect; generalized circuit constants; circle diagrams. Economic operation of power systems; driving point and transfer impedances. Solution of load flow, economic operation, and driving point and transfer impedance problems on the analog and digital computer.

555. Integrated Power System. *Prerequisite: Elec. Eng. 410. (3).*
Symmetrical and unsymmetrical faults; steady state and transient stability; economic control of integrated systems; solution of problems in each of the above topics 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). Coding Theory. *Prerequisite: Math. 425. (3).*
Coding theory as derived from probabilistic considerations. Introduction to information theory. Classifications of codes; Kraft condition codes, Shannon, Huffman, and Gilbert-More alphabetic codes. The Chernoff and Sterling approximation techniques, average upper and lower performance bounds for random, group, and convolution codes. Properties of simplex, orthogonal, and biorthogonal 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.

571. **Introduction to Neurophysiological Systems.** *Prerequisite: Elec. Eng. 445 or Info. and Cont. Eng. 570. (3).*
Application of systems theory to neurophysiology; a theoretical and experimental study of the application of linear and nonlinear systems theory, state-space concepts, and stability criteria to several neurophysiological systems; neuromuscular systems, pupillary control, eye tracking, temperature regulation, and central nervous system function.

573(Zoology 573). **Bioelectrical Measurements.** *Prerequisite: mathematics, physics, and chemistry; graduate standing; and permission of instructor. I and II. (4).*
Techniques and problems associated with measurements from biological systems. Topics to be covered include electrodes, transducers, bioelectric amplifiers, recording and telemetering systems, the nerve as a signal generator, biological impedances, volume conduction and analysis of complex waveforms. Lectures, demonstrations and laboratory projects.

574. **Modern Optics.** *Prerequisite: Physics 402 and Elec. Eng. 620, or permission of instructor. (3).*
Fundamentals of interference and diffraction theory; partial coherence and the general theory of image formation; the special cases of completely coherent and incoherent illumination; application to resolution and spatial frequency response of optical systems; diffraction theory of aberrations; matrix formulation of imaging; concepts in statistical optics, including power spectra, correlation functions, information content of an image, and information capacity of an optical transmission channel.

575. **Seminar in Optics of Coherent and Noncoherent Electromagnetic Radiations.** *Prerequisite: Elec. Eng. 475 or permission of instructor. (3).*
Special topics of current research interest in the field of electro-optical sciences.

580. **Physical Processes in Plasmas.** *Prerequisite: Elec. Eng. 380 or 383 or permission of instructor. (3)* without a laboratory by permission of instructor; *(4)* with a laboratory. *(3 or 4).*
Collision theory; Liouville theorem; development of Boltzmann equation; diffusion and mobility in a plasma; conductivity tensor of an ionized plasma; Langmuir probes; hydromagnetic equations; introduction to wave phenomena in gaseous plasmas; microwave determination of plasma density and temperature. Lectures and laboratory.

583. **Quantum and Statistical Electronics.** *Prerequisite: Elec. Eng. 420 and 483 or equivalent. (3).*
Probability theory; quantum theory; atomic structure and the periodic table; atomic bonds; emission and absorption of radiation; dipolar selection rules; electron theory of solids; Kronig-Penny model.

592. **Vacuum and Material Techniques.** *Prerequisite: Elec. Eng. 380. (2).*
Vacuum systems including mechanical pumps, diffusion pumps and ion pumping systems; theory of vacuums, gauges and metering systems; physical and electrical properties of materials used in electron and solid-state devices; thin film preparation and measurements; evaporation and electron beam bombardment techniques; heliarc welding; crystal growing; glass properties and working. Lectures and demonstrations.

595(Meteor.-Ocean. 595). Topics in Space Research. *Prerequisite: permission of instructor. (3).*
Significant processes in the ionosphere and upper atmosphere (e.g. ionization, dissociation, diffusion, etc.). Solar electromagnetic and corpuscular radiation; formation of the ionosphere; heating mechanisms in the upper atmosphere. Trapped particles; interplanetary plasma; atmospheres of the planets. Measurement techniques and results of recent sounding rocket and satellite experiments.

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. Analytical Techniques for Communications Systems. *Prerequisite: Elec. Eng. 445 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. Magnetic Materials and Devices. *Prerequisite: Elec. Eng. 583. (3).*
Zeeman and Stark effects; resonance phenomena; maser and laser materials; ferromagnetic and ferroelectric properties of matter; spin-wave theory; ferrite devices; superconductivity.

628. Antenna Theory II. *Prerequisite: Elec. Eng. 528. (3).*
Integral equations of perfectly conducting antennas, techniques of solutions and application to cylindrical and slot antennas. Frequency independent antennas, broad-band loaded antennas. Radiators in lossy and ionized media. Antenna synthesis, realizability, optimization; use of orthogonal functions in synthesis problem. Signal processing antennas.

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 anistropic 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 process. 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. Introduction to Optimal Control Systems. *Prerequisite: Elec. Eng. 549 or permission of instructor. (3).*
Analysis and synthesis of optimal control systems utilizing classical transfer functions and state space methods; introduction of Pontryagin maximum principle, dynamic programming, method of steepest descent; function space methods for solving prescribed and probabilistic optimal system problems.

646. Nonlinear Control-System Theory. *Prerequisite: Elec. Eng. 445 or Info. and Cont. 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. 546 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.

660 (Com. Sci. 660). Algebraic Coding Theory. *Prerequisite: Math. 517 or 513. (3).*
Structure of group codes and cyclic codes using Galois field theory. Linear sequential shift registers and the structure of the following codes: Hamming, Reed-Muller, Bose-Chaudhuri, Fire, concatenated and convolutional codes. Decoding algorithms and the logical design of encoding and decoding circuitry.

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. Switching and Automata Theory. *Prerequisite: Elec. Eng. 467 or Com. Sci. 522, or permission of instructor.* II. *(3).*
Advanced procedures for switching circuit analysis and synthesis; extensions of the finite-state system concept; relations between automata and languages. Emphasis is placed on recent research results.

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.

680. Wave Propagation in Plasmas. *Prerequisite: Elec. Eng. 580 and 620, or permission of instructor. (3).*
Generalized treatment of wave propagation in dense anisotropic plasmas; surface waves on a plasma column; acoustic waves; MHD waves; instabilities; relativistic effects; power absorption and radiation; Alfvén and ion cyclotron waves in plasmas.

687. Nonlinear Interaction Theory for Beams, Waves and Plasmas. *Prerequisite: Elec. Eng. 480, 580 or permission of instructor. (3).*
Formulation of general nonlinear interaction theory for electron beam and plasma devices; steady-state solution by Lagrangian techniques and application to klystrons, traveling-wave devices and crossed-field devices; consideration of transient behavior; solution of the nonlinear Boltzmann-Vlasov equation, analysis of instabilities and noise.

688. Semiconductor Materials and Devices. *Prerequisite: Elec. Eng. 583. (3).*
Properties of and transport phenomena in metals and semiconductors; electrical and thermal conduction; thermoelectric effects; absorption and emission of radiation; junction theory; microwave propreties of bulk semiconductors and junctions; device applications including recent developments.

689. Noise in Microwave and Quantum Devices. *Prerequisite: Elec. Eng. 686 or permission of instructor. (2).*
Statistical mechanics of multistream systems; medium-like models of an electron gas applied to electron streams, gases and solids; single velocity and Maxwellian streams; generation and propagation of noise; the one-dimensional model; the transmission-line analogy; noise factor of a linear-beam device and a transistor; noise in quantum mechanical systems; quantum detectors and masers.

690. Waves in Solid-State Plasmas. *Prerequisite: Elec. Eng. 480, 583 or permission of instructor. (3).*
Solid-state traveling-wave interactions, stability theory; acoustic waves; coupling factors and energy exchange in solid-state TWA's; electromagnetic and electrokinetic modes in solids, interaction of drifted carriers with optical modes; two-stream and transverse-wave instabilities in drifted plasmas; negative resistance in semiconductors, Gunn effect, avalanche diodes and noise in solid-state devices.

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 prinicples, 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 eliminated 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.

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(Astro. 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. (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. 720 or permission of instructor. (To be arranged).*
Study and discussion of currently active topics in electromagnetic field theory. This seminar may be repeated for credit.

830. Seminar in Microwave Theory. *Prerequisite: Elec. Eng. 530 or permission of instructor. (To be arranged).*
Selected topics of current interest. Typical areas of study: application of coupled-mode theory to nonuniform and inhomogeneous waveguides, mode conversion in curved waveguides, irregular-walled guides, synthesis of nonuniform lines and waveguides.

834. Seminar in Communication Theory and Applications. *Prerequisite: Elec. Eng. 430 or 534 or permission of instructor. (2).*
Selected topics of current interest in statistical communication theory and the theory of signal detectability. Typical areas of study: receiver design based on the likelihood ratio and total error probability, determination of probability density functions using matrix and integral methods, coherent and incoherent signal detection, and the learning and tracking of unknown or slowly changing signals.

845. Seminar on the Theory of Adaptive and Optimalizing Control Systems. *Prerequisite: Elec. Eng. 549 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. 549 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: permission of instructor. (To be arranged).*
Special topics in physical electronics from the fields of gas plasmas, solid-state devices, microwave beam devices and quantum devices. Discussion of recent periodical literature and current research topics.

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 multi-stage sounding rockets.

990. Doctoral Thesis. *(To be arranged).*

Engineering Graphics

Department Office: 412 West Engineering

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, III*a*, and III*b*. *(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.

104. Descriptive Geometry. *Prerequisite: Eng. Graphics 101 or Sci. Eng. 110.* I, II, III*a*, and III*b*. *(2)*.
Application of the principles of geometry and orthographic projection to the description of engineering devices. The relationships of points, lines, and planes; the graphical measurement of distances and angles; the determination of intersections of planes and curved surfaces with straight lines, curved lines, planes, and surfaces.

141. Mechanical Drawing for Foresters. *(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 forestry student will later have contact.

232. Graphical Analysis and Computation. *Prerequisite: permission of instructor. (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 104. (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. (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

Department Office: 201 West Engineering

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.

310. Statics and Stresses. *Prerequisite: Physics 145 and Math. 214 or 316.* 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 319.* 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.

319. Mechanics of Solids I. *Prerequisite: Eng. Mech. 218 and 345 and preceded or accompanied by Math. 316.* I and II. *(4).*
Simulation of behavior by elastic, plastic and visco-elastic materials models. Structural members subject to axial force; static indeterminancy; virtual work and energy methods. Stress and strain tensors; stress-strain relations; yield and flow criteria. Torsion of circular rods and tubes. Approximate theories of bending and shear in beams; virtual work and energy methods for frameworks in bending. Elastic instability. Lectures and laboratory.

324. Fluid Mechanics. *Prerequisite: Eng. Mech. 208 or 310 and Math. 214 or 316. I and II. (3).*
Principles of mechanics applied to liquids and gases. Dynamic similitude; special topics; manometers, Venturi and orifice meters, equilibrium of floating bod-

ies, 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. 316.* 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 316.* 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. 316.* I and II. *(3).*
Kinematics, rectilinear and curvilinear motion. Coriolis' acceleration, kinetics of particles and bodies, d'Alembert's principle, momentum, conservative and nonconservative 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 319, Math. 316.* I. *(3).*
Review of plane stress-strain relationships; fundamentals of photoelastic method of stress determination using transmission polariscope and methods of separating principal stresses; theory and application of brittle coatings; fundamentals of moiré fringe method of strain analysis; techniques of mechanical, optical, and electric resistance strain gages and related circuitry. Lectures and laboratory experiments.

403. Experimental Mechanics. *Prerequisite: Eng. Mech. 210 and 343, and Elec. Eng. 314 and 315.* 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 319.* 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, preceded or accompanied by Math. 450 or permission of instructor.* 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.

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, preceded or accompanied by Math. 450 or permission of instructor.* 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.

442. Intermediate Dynamics. *Prerequisite: Eng. Mech. 343 or equivalent, Math. 450 or permission of instructor.* I. *(3).*
Analytical mechanics for particle and rigid body motions. Lagrange's equations; introduction to Hamilton's development of mechanics; small vibration theory; special relativity; Hamilton-Jacobi equations; application of variational calculus.

507. Theory of a Continuous Medium I. *Prerequisite: Eng. Mech. 412, 422.* I. *(3).*
The general theory of a continuous medium. Kinematics of large motions and deformations; stress tensors; conservation of mass, momentum and energy; discontinuity requirements; restrictions on constitutive equations from thermodynamics; invariance requirements; constitutive equations for elasticity, viscoelasticity, plasticity, and fluids; applications for special deformations.

514. Theory of Elasticity I. *Prerequisite: Eng. Mech. 412 or equivalent.* II. *(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 anistrophy, 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.

517. Theory of Linear Viscoelasticity I. *Prerequisite: Eng. Mech. 412, Math. 447 or equivalent.* II. *(3).*
Viscoelastic stress-strain relations; generalized creep and relaxation models, operational approach. Correspondence between viscoelastic and elastic solutions of boundary value problems. Three-dimensional theory of linear viscoelastic media. Quasi-static problems; sinusoidal oscillation problems; use of complex modulus and compliance; dynamic problems, impact.

518. Theory of Elastic Stability I. *Prerequisite: Eng. Mech. 412 or equivalent. II. (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.* I. *(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.* I. *(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, Kármán-Tsien method; supersonic flows, Riemann's nonlinear treatment of finite waves, nonlinear expansion flows, Prandtl-Busemann method of characteristics; shock waves; wave motion of a conducting fluid in an electromagnetic field.

525. Non-Newtonian Fluid Mechanics. *Prerequisite: any one of the following: Eng. Mech. 326 or 422, or Civ. Eng. 524, or Mech. Eng. 521, or Aero. Eng. 420, or Chem.-Met. Eng. 341.* II. *(3).*
Non-Newtonian continuous media; flow classifications, stress-strain, rate-of-strain, laminar shear flow models for developed and boundary layer flows, stability compared to Newtonian case, turbulent flows. Flows of nonhomogeneous systems; non-Newtonian fluids *vs.* non-Newtonian behavior of particulate and multiphase media, laminar and turbulent shear flow models, rigid-particle suspensions, flexible-particle suspensions, gas-liquid flows. Momentum and energy transport and relation to boundary shear and other problems.

527. Thermodynamics. *Prerequisite: Math. 450 or permission of instructor.* 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.

535. Modelling and Analysis in the Bio-Sciences. *Prerequisite: Math. 450 and 552 or 554, or permission of instructor. (3).*
Mathematical modelling and techniques for solving some problems in the biosciences, ion exchange processes in fixed columns; diffusion kinetics in connection with some ideas of stability of metabolizing systems and cell division; unequal ventilation of the lung; introduction to aerosol mechanics, filtration, Smoluchowski's theory of coagulation, particle retention in the respiratory tract; Hodgkin and Huxley theory of membrane current and its application to conduction and excitation in nerve fibers.

541. Intermediate Vibration Theory. *Prerequisite: Eng. Mech. 442 or permission of instructor.* II. *(3).*
Free and forced vibration of lumped systems; vibration of multi-mass systems, normal modes, mechanical impedance, vibration control, matrix methods, Raleigh's method, and energy methods for approximate solutions.

543. History of Dynamics. *Prerequisite: Eng. Mech. 343 and Math. 316. (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. 442. (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 442, 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. Rigid Body Dynamics. *Prerequisite: Eng. Mech. 442 or permission of instructor. (3).*
Kinematics of rigid body motion; orthogonal transformations and transformation matrix, Eulerian angles, Euler's Theorem. Dynamics of rigid body motion; Euler and Poisson equations of motion, the Poinsot construction, the case of Kovalevskaya, application of Lie Series, the self excited and the externally excited rigid body, gyrodynamics, gyroscopic instruments, general motion of several coupled rigid bodies.

548. Lattice Dynamics. *Prerequisite: Eng. Mech. 442, Math. 552 or 554 or permission of instructor.* II. *(3).*
Lattice dynamics and micromechanics of solids with emphasis on the elastic

constants and thermodynamic properties of crystal structures. Elastic wave propagation in 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. 450 or permission of instructor.* 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 II. *Prerequisite: Eng. Mech. 507, and Math. 653 or equivalent.* II. *(3).*
Generalization of the theory of a continuous media to general co-ordinates; compatibility and integrability relations; theory of constitutive equations; hypoelasticity.

714. Theory of Elasticity II. *Prerequisite: Eng. Mech. 514.* I. *(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.* II. *(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. Dynamics of Nonhomogeneous Fluids. *Prerequisite: Eng. Mech. 422 or permission of instructor.* I. *(3).*
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. Theory of Hydrodynamic Stability. *Prerequisite: Eng. Mech. 422 or permission of instructor.* I. *(3).*
Treatment of hydrodynamic equations in general co-ordinates by tensorial meth-

* For description see Eng. Mech. 412 and 422 or Detroit Extension Service bulletin.

ods; gravitational, hydromagnetic, and surface-tension instabilities; instability of rotating fluids and of flow in porous media. Tollmien-Schlichting waves; instability of free-surface flows.

726. Singular Perturbation and Approximate Methods in the Mechanics of Fluids I. *Prerequisite: Eng. Mech. 523, Math. 554 (or 552 and 555), or permission of instructor.* I. *(3).*
Review of perturbation theory; Poincaré method, Lighthill and Whitman extension, elementary singular perturbation. Viscous damping of wave motion, oscillation in weakly nonlinear systems, the two-time method. Boundary layer flow, inner and outer expansions, optimal co-ordinates in singular perturbation theory; phenomena in rotating flows.

727. Singular Perturbation and Approximate Methods in the Mechanics of Fluids II. *Prerequisite: Eng. Mech. 523, Math. 554 (or 552 and 555), or permission of instructor.* II. *(3).*
Van Dyke's theory on viscous flows, modified Oseen method, Wiener-Hopf technique, substitute kernel methods as applied to fluid mechanics. Shock singular perturbation theory.

741. Nonlinear Oscillations. *Prerequisite: Eng. Mech. 442, Math. 404 and 450, or permission of instructor.* II. *(3).*
Methods of treating the motions of nonlinear mechanical systems; phase-space and phase-plane δ methods: notion of singularities; stability in the sense of Liapunov; equations integrable by elliptic integrals and functions; the perturbation method; the method of Kryloff and Bogoliuboff; Mathieu's equation and its application to the stability of nonlinear osciallations.

745. Wave Motion in Continuous Media. *Prerequisite: Math. 450 or equivalent.* II. *(3).*
Wave propagation in bounded and extended elastic media, including transmission, reflection, and refraction phenomena, transient-stress states, and analogies with acoustical ad 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.

811. Seminar in Mechanics of Solids. *(To be arranged).*

821. Seminar in Mechanics of Fluids. *(To be arranged).*

841. Seminar in Dynamics. *(To be arranged).*

855. Seminar in Molecular Mechanics. *Prerequisite: Eng. Mech. 555 or permission of instructor. (To be arranged).*
Current research in the applications of statistical mechanics and kinetic theory to the dynamics of media in the continuum range; selected topics in dense gases, liquids, and solids.

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

Department Office: 3516 Natural Resources

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 in English 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 is usually elected during the first term of the freshman year and English 112 during the second term. English 121, the speaking course, may be elected either term. Students with outstanding ability can be exempted from one or more of these courses.

111. Freshman Composition I. I, II, and normally III*b*. *(3).*
A course in the essentials of composition that stresses sentence structure, paragraph development and theme organization, with particular emphasis on various techniques of exposition and argument, such as analysis, comparison, and definition. Essays are analyzed to provide models and ideas for themes and to develop skill in reading.

112. Freshman Composition II. *Prerequisite: English 111, preceded or accompanied by English 121.* I, II, and normally III*a*. *(2).*
A course in which the skills learned in English III are reinforced and extended by applying them to subjects drawn from readings in poetry, drama, and prose fiction. The aim is to continue the student's training in both analyzing complex problems and developing the analysis into an essay or report that effectively transmits its information to the reader.

121. Introductory Speech. I, II, and normally III*b*. *(1).*
A course in the preparation and delivery of 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: Special Electives in Humanities

To serve the need for three-hour electives in the humanities for engineering students—freshmen to seniors—the English Department offers these three courses. They differ from Group II and III courses in three respects:
(1) there are no prerequisites: (2) they focus almost entirely on reading and discussion and require relatively little writing; (3) they are interdisciplinary.

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 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. 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, II, and normally III*a* and III*b*. *(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 Fiction. *Prerequisite: English 111, 112, and 121.* I, II, and normally III*a*. *(2).*
Intensive reading of prose fiction, with emphasis on the short story, by such major authors as Conrad, Joyce, Faulkner, Hemingway, and Steinbeck.

263. Modern Plays: Ibsen to the Present. *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 Saleman.*

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 junors, 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. (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.

419. Major Speeches in American History. ***Prerequisite: English 111, 112, 121,*** *and, ordinarily, one course in Group II.* I and II. *(2).*
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)*; may be offered III*a* or III*b*. *(2).*
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. Major Plays: Aeschylus to Ibsen. *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(2).*
Drama from the Greek period through the nineteenth century, that is of particular significance to the modern world because of philosophical, social, and psychological concerns. Sophocles, Shakespeare, Moliére, Musset, and Chekhov are examples of dramatists who may be discussed.

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.

468. Readings in Asian Literature. *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(3).*
A study of selected translations of major Asian works of prose, poetry, and drama, both ancient and modern. The course is designed to acquaint the student with major Asian literary, philosophical, and religious traditions, including the Indian epics, Southeast Asian lyric poetry, Buddhist scriptures, Japanese drama, etc. Lectures and discussion.

475. American Literature. *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(3);* normally offered III*a* and III*b*. *(2).*
A survey of American writing from the colonial period to the present. The course concentrates on those authors who best represent the significant intellectual and literary trends of the past and who are valuable for an understanding of the present. Typical authors studied are Poe, Hawthorne, Melville, Whitman, Twain, Faulkner, and O'Neill.

485. Literary Masterpieces. *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(2 or 3);* normally offered III*a* and III*b*. *(2).*
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, and Maupassant.

488. Literature and Modern Thought. *Prerequisite: English 111, 112, 121, and, ordinarily, one course in Group II.* I and II. *(3);* may be offered III*a* or III*b*. *(2).*
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 embodying these intellectual conceptions, 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; normally offered III*a* and III*b*. *(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 their literary significance.

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.

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 112.* I and II. *(2).*
Preparation and delivery of informative and persuasive speeches. The student is given opportunity to improve his ability to speak effectively, and to listen critically. He will choose his own subjects and work with his own ideas, feelings, and experiences.

498. Argumentation and Debate. *Prerequisite: English 111, 112, and 121.* I and II. *(2).*
Training in the organization and delivery of the principal types of persuasive speeches, with emphasis on conference speaking and debating.

499. Scientific and Technical Writing. *Prerequisite: English 111, 112, and 121.* I, II; may be offered III*a* or III*b*. *(2).*
The fundamentals of scientific and technical writing with emphasis on clear and orderly exposition.

Geology and Mineralogy*

Department Office: 2051 Natural Science

Professor Dorr: Professors Arnold, Briggs, Eschman, Goddard, Heinrich, Hibbard, Hough, Kelly, Kesling, Landes, Stumm, Turneaure, and Wilson; Associate Professors Cloke, Farrand, Peacor, and Pollack; Assistant Professors Clark, Macurda and Smith; Lecturers Freed and McClurg.

111. Introductory Geology. *Not open to those who have had Geol. 218, 219, or 120,* 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.

* College of Literature, Science, and the Arts.

120. Physical Geology. *Prerequisite: Two years of high school mathematics and one year of high school chemistry. Not open to those who have had Geol. 111, 113, 218, or 219.* II. *(4).*
An introductory course in geology, with emphasis on quantitative and mathematical aspects of the science. Lectures, laboratory, problems.

218. Geology for Engineers. II. *(3).*
Lectures on general geology with special emphasis on surficial phenomena of particular interest to engineers, such as rocks, weathering, soils, and landscape development. Laboratory includes rock and mineral identification, and the interpretation of topographic and geologic maps and aerial photographs. Geol. 218 is required of students in civil engineering and is open to others as an elective. Lectures, laboratory, and campus field trips.

219. Geology and Man. *Not open to freshmen, or those who have had Geol. 111, 120, or 218.* 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, and also Geol. 280, Minerals and World Affairs are especially useful for engineering students.

Industrial Engineering

Department Office: 231 West Engineering

371. Stochastic Industrial Processes. *Prerequisite: Math. 465 and preceded or accompanied by Math. 316.* I and II. *(3).*
Elementary concepts in renewals, compound processes, Markov processes, queueing and related topics. Applications of the concepts to replacement strategy, machine repair strategy, demand and service analysis, and other areas of industrial processes.

375. Engineering Linear Programming. *Prerequisite: Math. 315.* I and II. *(2).*
An introduction to formulation of linear optimization models, the simplex algorithm, transportation and assignment algorithms, and their engineering applications.

***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 Ind. Eng. 371 and 375, 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.

* Students not enrolled in the industrial engineering program and not presenting the usual prerequisite may elect these courses with permission of the department.

***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, 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. 371 and 375.* 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, 371 and 375.* 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: Math. 315.* I and II. *(3).*
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 Math. 465.* I and II. *(4).*
The analysis and prediction of the performance of humans in industrial and service type man-machine systems. The use of predetermined time systems, learning curves, operator selection procedures, work sampling, and motion economy principles in the design of the work place.

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: A course in statistics.* 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.

469. Industrial Engineering Computations. *Prerequisite: Math. 465 and 466. I* and II. *(3).*
Deals with computational aspects of common statistical problems. About five computational projects will be assigned during the term. All computational work can be done in the laboratory on desk calculators. Two hours of recitation and one three-hour laboratory session each week.

472. Operations Research. *Prerequisite: preceded or accompanied by Math. 465.* I and II. *(3). Not open to undergraduate Ind. Eng. students.*
Introduction to operations research; the methodology of mathematical models and its application to various industrial problems, including queueing theory,

* Students not enrolled in the industrial engineering program and not presenting the usual prerequisite may elect these courses with permission of the department.

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 315 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.

478. Computer Graphics. *Prerequisite: senior or graduate standing.* I. *(3).*
Introduction to on-line programming systems and graphic input-output systems including cathode ray tube devices, automatic drafting machines, and plotters. Description of principles of computer-aided design. The application of data structures in the analysis of drawings and lists. Geometric manipulation for computer use. Examples of drafting languages, animated movies, and surface representation.

483(Mech. Eng. 483). Numerical Control of Manufacturing Processes. *Prerequisite: Ind. Eng. 473 or Mech. Eng. 482 and permission of instructor.* II. *(3).*
Basic elements of numerical control of metal processing systems: development of programming languages for point to point and contouring machines; interaction between geometry and machinability decisions. Laboratory experiments in optimizing part programming and equipment utilization. Two one-hour lectures and one two-hour laboratory.

490. Directed Study, Research and Special Problems I. *Prerequisite: permission of department.* I, II, III, III*a* and III*b*. *(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 industrial engineering including management, work measurement, methods, organization, industrial sciences, industrial mathematics, systems, and procedures.

495. Seminar in Hospital Systems. *Prerequisite: permission of department. I* and II. *(3).*
Individual or group study of hospital systems. Topics may be chosen from any of the areas of industrial engineering including management, work measurement, methods, organization, 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. Industrial Engineering Readings. *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: graduate standing.* 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 $25 laboratory fee is required.

527. Engineering Decision Theory. *Prerequisite: Ind. Eng. 451 and Math 465 or permission of department.* I and II. *(3).*
An introduction to normative decision models and their applications. Decisions under risk and uncertainty with applications to include equipment investment, bidding, purchasing, and diversification policies. Basic elements of utility theory, statistical decision theory, and game theory.

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. 371, 375 or 472.* 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, 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.

549. Automatic Process Control I. *Prerequisite: Math. 404.* II. *(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.

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 discussions 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.

567. **Linear Statistical Models and Their Application I.** *Prerequisite: Math. 466.* I. *(3).*
Study of linear statistical models applicable to industrial problems. Multivariate normal distribution, noncentral F distribution. General linear-hypothesis model of full rank, including estimation of parameters and tests of hypotheses about the parameters using analysis of variance.

568. **Linear Statistical Models and Their Application II.** *Prerequisite: Ind. Eng. 567.* II. *(3).*
Continuation of Linear Statistical Models I. Linear regression models; fixed-effects, random-effects, and mixed effects analysis of variance models. Factorial experiments and their relation to linear models. The use of linear models to analyze fractional replicates of factorial experiments. Strong emphasis will be placed on the choice of models to fit real situations and the appropriate analysis of data.

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. **Introduction to Linear Programming.** *Prerequisite: preceded or accompanied by Math. 517.* I. *(3).*
An introduction to linear programming. Primary attention is focused on variants of the simplex algorithm and on algorithms for the transportation problem. Examples of uses of linear programming and machine codes for solution are discussed and used.

576. **Nonlinear Programming.** *Prerequisite: Ind. Eng. 371 and 375. II. (3).*
Various integer and nonlinear problems. Gradient methods and the concepts of dynamic programming.

581. **Military Systems and Operations Analysis.** *Prerequisite: Ind. Eng. 371, 375 or equivalent.* II. *(3).*
Application of engineering, operations research, and economic principles to op-

* Students not enrolled in the industrial engineering program and not presenting the usual prerequisite may elect courses idicated by * with the permission of the department.

erational analysis and planning for military systems. Topics include: history of military operations analysis, Department of Defense planning procedures, prediction of weapon system capabilities, target acquisition and search theory, combat dynamics, cost estimation, logistics planning procedures, force composition, integration of cost/effectiveness information for decision making.

590. Directed Study, Research and Special Problems II. *Prerequisite: Ind. Eng. 490.* I, II, III, III*a* and III*b*. *(to be arranged).*
Continuation of Ind. Eng. 490.

598. Selected Topics in Computer Graphics. *Prerequisite: Ind. Eng. 473, Math. 473, or Ind. Eng. 478.* I. *(to be arranged, maximum of 3).*
Individual or group study of topics in computer graphics. Designs or experiments with computer graphics facilities, including cathode ray tube devices, automatic drafting machines, plotters. Topics may be chosen from any engineering or allied discipline, provided that the study or project emphasizes the methodology of computer graphics.

600(Hosp. Admin. 701). Research Seminar in Hospital and Medical Systems. *Prerequisite: permission of instructor.* I and II. *(to be arranged).*
The use of quantitative techniques in hospital and medical care research. Discussion and review of current research and related methodological techniques in this area of interest. Use of outside speakers for presentation of selected research topics. Student involvement through readings, surveys, and development of research projects.

608. Seminar in Computer Graphics. *Prerequisite: Ind. Eng. 598 or permission of instructor.* I and II. *(to be arranged).*
Selected lectures and readings on recent developments in computer graphics.

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.

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.

675. Topics in Linear Programming. *Prerequisite: Ind. Eng. 575 or permission of department.* II. *(3).*
Selected topics at the level of integer and mixed integer programming, decompo-

sition, and stochastic linear programming, with emphasis on computer algorithms.

681. Topics in Military Systems and Operations Analysis. *Prerequisite: Ind. Eng. 581 and permission of instructor.* I. *(3).*
Advanced study in selected topics of Ind. Eng. 581.

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 problems involved in planning and controlling industrial change. Considers the firm as a unit continuously integrating production, marketing, 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. 549.* II. *(3).*
Continuation of Ind. Eng. 549 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. *(To be arranged).*

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).*

Information and Control Engineering

Department Office: 1525 East Engineering

500. Linear Systems I. *Prerequisite: preceded or accompanied by Math. 448. (3).*
Introduction to matrices, vectors, and finite dimensional linear spaces. Applications to linear differential and difference equations: the fundamental matrix, variation of parameters, adjoint systems. Concept of system state. Input-output

relations. Laplace and z-transforms, transfer functions and frequency response, weighting functions, and time response.

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: a course in differential equations. (2).*
Concept of feedback control. Transient and steady-state analysis of linear control systems with command inputs and disturbances. Introduction to transfer operators. Influence of simple nonlinearities on control system design. Synthesis of linear control systems using root-locus diagrams. Sinusoidal response of linear systems and the use of Nyquist plots for analysis and synthesis. Gain-phase relationships and the application of Bode plots to control system design.

571. Automatic Control Laboratory I. *Prerequisite: preceded or accompanied by Info. and Cont. Eng. 570. (1).*
Introduction to the differential analyzer; its application to simulation of control systems presented in Info. and Cont. Eng. 570; the differential analyzer as a design tool. Examples of actual feedback systems; determination of system characteristics from input-output records; operational amplifiers as control elements.

610. Introduction to Hybrid Computation. *Prerequisite: Info. and Cont. Eng. 510 or equivalent. (3).*
Description of combined analog-digital computer systems. Introduction to patchable logic. Dynamic error analysis of analog, digital, and hybrid computing systems using operational methods, including the z-transform. Application of hybrid computers to parameter optimization problems and partial differential equations. Lecture and laboratory.

620. Introduction to Nonlinear Systems. *Prerequisite: Math. 404, Info. and Cont. Eng. 500 or permission of instructor. (3).*
Study of nonlinear systems with emphasis on the autonomous case, including the following: concept of phase space; linearization; 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.

621. Simulation and Solution of Nonlinear Systems. *Prerequisite: Info. and Cont. Eng. 510 and preceded or accompanied by Info. and Cont. Eng. 620 or permission of instructor. (1).*
Supervised work on assigned problems and problems of interest to the student of the types treated in Info. and Cont. Eng. 620 and 720. The principal tool used is the electronic differential analyzer.

630. Random Processes in Linear Systems. *Prerequisite: Math. 448 preceded or accompanied by Info. and Cont. Eng. 500 and a course in probability. (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: Info. and Cont. Eng. 630, 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: preceded or accompanied by Info. and Cont. Eng. 640. (1).*
Laboratory experiments involving the various modulation and multiplex methods and associated instrumentation described in Info. and Cont. Eng. 640.

660. Theory and Design of Measuring Systems. *Prerequisite: Info. and Cont. Eng. 630. (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 Info. and Cont. Eng. 660. (1).*
Laboratory experiments covering the measurement theory given in Info. and Cont. Eng. 660.

670. Principles of Automatic Control II. *Prerequisite: Info. and Cont. Eng. 570 and Math. 448 or equivalent. (3).*
Application of describing function methods to nonlinear control systems. Use of the phase plane for analysis of second-order control systems and synthesis of second-order time-optimal control systems. Analysis of operational amplifiers and their application to control system design. Design methods for ac carrier systems. Introduction to the z-transform and its application to digital and mixed-data systems. Analysis and synthesis of sampled-data control systems. Design of control systems for minimum sensitivity to parameter variation.

671. Automatic Control Laboratory II. *Prerequisite: preceded or accompanied by Info. and Cont. 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.

674. Optimal Control I. *Prerequisite: Info. and Cont. Eng. 500. (3).*
Review of mathematical foundations. Formulation of optimal control problems. Optimal control theory: the principle of optimality, Hamilton-Jacobi theory, the Pontryagin principle. Design of optimal systems: linear systems with quadratic criteria, minimum time and minimum fuel designs. Applications.

700. Linear Systems II. *Prerequisite: Info. and Cont. Eng. 500. (2).*
Time-varying linear systems. Periodic systems and Floquet theory. Qualitative properties of system response: stability, controllability, and observability. Introduction to normed spaces and applications to such topics as linear distributed systems and systems with time delay.

720. Theory of Nonlinear System Response. *Prerequisite: Info. and Cont. Eng. 620. (2).*
Response of nonlinear systems to periodic inputs. Harmonic, subharmonic responses and frequency entrainment of sinusoidally-driven systems. Stability of periodic solutions. Floquet theory, Hill's equation, Mathieu's equation and applications. Topics of current interest including theorems on existence, uniqueness of periodic solutions, and validity of solutions predicted by classical methods.

730. Random Processes in Systems Analysis. *Prerequisite: Info. and Cont. 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, Info. and Cont. Eng. 730 or Elec. Eng. 634 or equivalent. (To be arranged).*
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.

772. Special Topics in Automatic Control. *Prerequisite: Info. and Cont. Eng. 630 and 674 or permission of instructor. (To be arranged).*
Topics of current research interest to be selected from such areas as: computational methods in optimal control, stochastic control, stability, adaptive systems, control of distributed systems.

774. Optimal Control II. *Prerequisite: Info. and Cont. Eng. 674 or permission of instructor. (3).*
Existence of optimal controls. Control of discrete time systems. State variable constraints. The computation of optimal controls, including solution of two point boundary value problems, convexity methods, dynamic programming, and other techniques. Applications and topics of current interest.

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 information and control engineering.

902. Research. *(To be arranged).*
Specialized individual or group problems of research or design supervised by a member of the staff.

Mathematics*

Department Office: 3217 Angell Hall

Professor LeVeque; Professors Bartels, Brown, Brumfiel, Cesari, Coburn, Darling, Dolph, Dwyer, Ellis, Fischer, Galler, Gehring, Halmos, Harary, Hay, Heins, Higman, P. S. Jones, Kaplan, Kazarinoff, Kister, Lewis, Lyndon, Mayerson, McLaughlin, Nesbitt, Piranian, Raymond, Reade, Robbins, Shapiro, Shields, Spivey, Thrall, Titus, Ullman, and Wendel; Associate Professors Dickson, Douglas, Duren, Ericson, Federbush, Goldberg, E. Halpern, Hicks, Hill, D. A. Jones, Kincaid, Leisenring, Livingstone, Pearcy, Ramanujan, and Rosen; Assistant Professors Bagby, Berk, Bowers, Burdick, Chafee, Cohn, J. Halpern, Harvey, Hedstrom, Kessler, Krause, Lee, Moler, Peterson, Schafer, Schwartz, Shih, Smoller, Stark, Stenger, Storer, Taylor, Thomas, Wallen, and Williams; Hildebrandt; Instructors Dyer, Goldstein, Hinman, and Lininger.

105. 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. (No credit for students presenting more than three years of high school mathematics.)

107. 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). (No credit for students presenting high school credit for trigonometry).*
Includes the trigonometry of Math. 105.

115. 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. (Math. 107 may be taken concurrently.)* 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. 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, polar co-ordinates.

185, 186. 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 350.

195, 196. 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, 495 includes the content of Math. 115, 116,

* 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.

315, 316, 451, with deeper penetration into many topics and with additional material.

213, 214. Calculus I and II. *Prerequisite: for 213, a semester of college analytic geometry; for 214, 213.* I and II. *(4 each).*
This sequence includes the calculus content of Math. 115, 116 and the material of Math. 215 and 315.

215. Analytic Geometry and Calculus III. *Prerequisite: Math. 116.* I and II. *(4).*
Vector algebra, solid analytic geometry, partial derivatives, vector calculus, multiple integrals.

216. Calculus and Differential Equations. *Prerequisite: Math. 215.* I and II. *(4).*
Includes the material of Math. 315 (2) and Math. 316 (2). Prospective mathematics majors should elect Math. 350 and 316 instead.

273. Elementary Computer Techniques. *Prerequisite: to be preceded by or taken concurrently with Math. 186, 196, 213, or 215.* I and II. *(2).*
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. 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. 316 and 404 with some deeper penetrations.

295. Introduction to Modern Algebra. *Prerequisite: Math. 196 and membership in departmental Honors program, or permission of counselor.* I. *(4).*
An introduction to modern algebra with emphasis on polynomial and linear algebra. Designed primarily for mathematics Honors students who have had Mathematics 195 and 196.

296, 495, 496. Analysis I, II, III. *Prerequisite: Math. 195, 196, and 295.* 495 and 496, I, *(3 each);* 296, II, *(4).*
Analysis I: Multivariable differential calculus: Analysis II: multivariable integral calculus: Analysis III: Differential equations. Designed primarily for mathematics Honor students who have had 195, 196, and 295. The material covered is approximately that of Mathematics 316, 404, 451, and 452 but there is a deeper penetration into many topics.

315. Infinite Series. *Prerequisite: Math. 215.* I and II. *(2).*
A re-examination of the limit concept; infinite sequences; infinite series; power series; trigonometric series.

316. Introduction to Differential Equations. *Prerequisite: to be preceded by or taken concurrently with Math. 214, 315 or 350.* I and II. *(2).*
Solutions and applications of differential equations of the first order, linear equations with constant coefficients, solutions by means of power series.
Note.—Math 315 and 316 together are equivalent to Math. 216.

350. Analysis and Modern Algebra. *Prerequisite: Math. 214 or 215, open only to prospective mathematics majors.* I and II. *(3).*
Set theory and cardinal numbers; groups, coset decomposition; integral domains; construction of real number system; limits and sequences; continuity; series convergence tests, power series, Taylor's theorem. This course provides

mathematics majors with a more rigorous introduction to the analysis and modern algebra required in subsequent concentration courses.

365, 366. Introduction to Statistics I and II. *Prerequisite: to be preceded by or taken concurrently with Math. 214 or 316; Math. 366: 365.* I and II. *(3).*
Basic concepts of probability; expectation, variance, covariance; distribution functions; bivariate, marginal and conditional distributions; treatment of experimental data; normal sampling theory; confidence intervals and tests of hypotheses; introduction to regression, and to analysis of variance. Applications to problems in science and engineering are emphasized. (This sequence is virtually identical to 465-466 but is for undergraduate students only.)

404. Differential Equations. *Prerequisite: Math. 316.* I and II. *(3).*
Systems approach to linear differential equations and physical applications. Simultaneous linear equations, solution by matrices. Power series solutions. Numercial methods. Phase plane analysis of nonlinear differential equations.

405. Differential Equations. *Prerequisite: freshman and sophomore mathematics, including a full treatment of calculus.* I. *(4; 2 for students with full credit for Math. 316).*
The material on differential equations covered in Math. 316 and 404.

412. First Course in Modern Algebra. *Prerequisite: Math. 350 or permission of counselor.* I and II. *(3).*
Integers, rational numbers, real numbers, complex numbers, Fields and domains. Polynomials. Divisibility. Solution of polynomial equations. Symmetric functions. Determinants.

417(517). Matrix Algebra I. *Prerequisite: Three terms of college mathematics.* I and II. *(3).*
Matrix operations; solution of linear equations; vector spaces and linear transformations; determinants (briefly); equivalence and introduction to congruence, similarity and orthogonal congruence. Intended primarily for students in fields other than mathematics. Students of mathematics elect Math. 513.

418. Matrix Algebra II. *Prerequisite: Math. 417.* II. *(3).*
Similarity theory; euclidean and unitary geometry; generalized inverse; equivalence relations, invariants, and canonical forms; selected applications.

425. Introduction to Probability. *Prerequisite: Math. 316.* I, II, and III*a*. *(3).*
Sample spaces, random variables, expectation, distributions; elementary limit theorems; applications.

433. Introduction to Differential Geometry. *Prerequisite: Math. 450, 451 or permission of instructor.* I and II. *(3).*
Curves and surfaces in three space, using advanced calculus. The Frenet formulas for a curve; the first and second fundamental forms of a surface; the Christoffel symbols and covariant differentiation on a surface; geodesics; intrinsic geometry of a surface.

440. Vector Analysis. *Prerequisite: Math. 316.* I. *(2).*
The formal processes of vector analysis, with applications to mechanics and geometry.

447. Modern Operational Mathematics. *Prerequisite: Math. 316 and preceded by or taken 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. Operational Methods for Systems Analysis. *Prerequisite: Math. 316 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 I. *Prerequisite: Math. 316.* I and II. *(4).*
Topics in advanced calculus including vector analysis, improper integrals, line integrals, partial derivatives, directional derivatives, infinite series. Students cannot receive credit for both Math. 450 and 451.

451. Advanced Calculus I. *Prerequisite: Math. 286 or 350 or equivalent. Intended for mathematics majors, other students desiring advanced calculus should elect Math. 450.* I and II. *(3).*
Calculus of functions of one variable, including their expansion into power series, and foundations of calculus of functions of two or more variables.

452. Advanced Calculus II. *Prerequisite: Math. 451 and 513 or 417 (513 or 417 may also be taken concurrently).* I and II. *(3).*
Multi-variable calculus, topics in differential equations, and further topics.

461. Statistical Analysis I. *No mathematics prerequisite, not open to students in mathematics.* I. *(3).*
Nature of statistics, distributions, measures of central value and dispersion, sampling, normal distribution, statistical inference, estimation and tests of hypotheses. Methods of computation, applications. Math. 461, followed by Math. 462, gives the student an introduction to basic methods of statistical analysis.

462. Statistical Analysis II. *Prerequisite: Math. 461.* II. *(3).*
Analysis of variance, regression and correlation, analysis of covariance, use of x^2, binomial distribution, Poisson distribution, power of a test, nonparametric statistics. Methods of computation, applications.

465, 466. Introduction to Statistics I and II. *Prerequisite: preceded by or taken concurrently with Math. 214 or 315.* I and II. *(3).*
Basic concepts of probability; expectation, variance, covariance; distribution functions; bivariate, marginal and conditional distributions; treatment of experimental data; normal sampling theory; confidence intervals and tests of hypotheses; introduction to regression, and to analysis of variance. Applications to problems in science and engineering are emphasized. No credit for graduate students in mathematics; such students should elect the sequence Math. 425, 468.

468. (562) Mathematical Statistics. *Prerequisite: Math. 425 and preferably 417.* I and II. *(3).*
Theories of statistical inference. Distributions important in statistics. Estimation and testing of hypotheses. Students may not receive credit for both Math. 466 and 468.

473(Com. Sci. 473). Introduction to Digital Computers. *Prerequisite: Math. 316; Math. 273 recommended.* 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 and System/360 computers.

513. Introduction to Linear Algebra. *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.

518. Linear Optimization. *Prerequisite: A course in linear algebra.* II. *(3).*
Linear inequalities, convex geometry, double description and duality; analysis of network flows: applications to linear programming, two-person zero-sum games and other topics.

525, 526. Mathematical Theory of Probability I and II. *Prerequisite: Math. 450 or 451; with permission of the instructor may be taken concurrently.* I and II. *(3).*
Axiomatic treatment of probability, with emphasis on discrete sample spaces. Sums of independent random variables, random walks, limit theorems; Markov chains and other stochastic processes.

552. Fourier Series and Applications. *Prerequisite: Math. 450 or 451.* I and II. *(3). (1 for students with credit for Math. 554).*
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.* I and 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. Introducton to Functions of a Complex Variable with Applications. *Prerequisites: Math. 450 or 451.* I and II. *(3). (1 for students with credit for Math. 554).*
Complex numbers; limit, continuity; derivative; conformal representation; integration; Cauchy theorems; power series; singularities; applications to engineering and mathematical physics.

556. Methods of Partial Differential Equations. *Prerequisite: Math. 450 and 555.*
An introduction to the theory of the Laplace transform and its application to the solution of linear partial differential equations. Additional topics in functions of a complex variable which are needed to develop the material. Asymptotic behavior of integrals which arise in the applications.

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.

558. Introduction to the Theory of Ordinary and Partial Differential Equations. *Prerequisite: Advanced calculus and some linear algebra, or permission of instructor.* I and II. *(3).*
Picard theorem, method of successive approximations, theory of characteristics for first and second order partial differential equations, the Cauchy-Kowalewski theorem, elementary classification of second order partial differential equations, elementary representation theorems.

559. Partial Differential Equations. *Prerequisite: Math. 555 and 558.* II. *(3).*
Green's functions for ordinary and linear elliptic partial differential equations,

especially Laplace's equation and the wave equation; the interior and exterior problems; Sturm-Liouville problems; distribution of eigenvalues, asymptotic properties of solutions; elementary discussion of Schwartz distributions.

564(665). Statistical Decision Theory I. *Prerequisite: Math. 468 or equivalent.* I. *(3).*
Utility and principles of choice, classes of optimal strategies, sufficient statistics, sequential games. Bayes and minimax criteria, comparison of experiments.

565. Least Squares and the Analysis of Variance. *Prerequisite: Math. 468 or permission of the instructor.* 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. 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.

567. Introduction to Multivariate Analysis. *Prerequisite: Math. 451, 417, 468 or permission of the instructor.* I. *(3).*
Multiple and partial correlation; the multivariate normal distribution; the T^2 statistic, the Wishart distribution and its properties; applications to discriminant analysis, classification problems, etc.; computational methods.

568. Topics in Multivariate Analysis. *Prerequisite: Math. 567.* II. *(3).*
Additional treatment of topics introduced in Math. 567; regression with multiple criteria; canonical correlation; distribution of characteristic roots; principal components and factor analysis.

569. Non-parametric Statistics. *Prerequisite: Math. 468 or permission of the instructor.* II. *(3).*
Methods of inference relevant when it is explicitly recognized that the form of the distribution is unknown. Sign test, Mann-Whitney test, Kolmogorov-Smirnov test, median tests; U statistics, estimation of a cumulative distribution function, rank correlation procedures; robustness.

571. Numerical Analysis I. *Prerequisite: Math. 404 or 450 or 451, and 273 or 473. (3).*
Mathematics 571 and 572 together provide a thorough treatment of the derivation, convergence, stability, efficiency and error of numerical methods. This course includes interpolation and quadrature. Numerical methods for ordinary differential equations. Solution of algebraic and transcendental equations. Approximation. Testing of methods on a computer.

572. Numerical Analysis II. *Prerequisite: Math. 417 or 513, and 273 or 473. (3).*
Usually preceded by Mathematics 571, but may be taken separately. Solution of simultaneous linear and nonlinear equations. Matrix inversion. Roundoff error analysis. Computation of eigenvalues of symmetric matrices. Introduction to methods for partial differential equations. Testing of methods on a computer.

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 macro-instructions, the structure and use of executive systems, list storage, threaded lists, and automatic programming languages.

592. Theory of Graphs. *Prerequisite: Math. 214 or 315.* I. *(3).*
Traversability problems, trees and cycles, matrices and groups associated with a graph, directed graphs, the embedibility of graphs in surfaces, separation and factorization problems, the four color conjecture.

593. Combinatorial Theory. *Prerequisite: Math. 316 or permission of the instructor.* II. *(3).*
Generating functions and enumeration, combinatorial properties of binary matrices, configurations and designs, permutation groups, and Latin squares. Applications to enumeration problems in organic chemistry, statistical mechanics and electric networks.

594. Intermediate Analysis for Engineers. *Prerequisite: Math. 450.* I and II. *(3).*
Basic ideas of advanced calculus, such as uniform continuity, with emphasis on rigorous proofs; some set theory and introduction to metric spaces; some linear algebra.

625. Probability and Random Processes I. *Prerequisite: Math. 601.* I. *(3).*
Axiomatics; measures and integration in abstract spaces. Fourier analysis, characteristic functions. Conditional expectation. Kolmogorov extension theorem. Stochastic processes: Wiener-Levy, infinitely divisible, stable. Limit theorems, law of the iterated logarithm.

626. Probability and Random Processes II. *Prerequisite: Math. 625.* II. *(3).*
Selected topics from among: diffusion theory and partial differential equations; spectral analysis; stationary processes, and ergodic theory; information theory; martingales and gambling systems; theory of partial sums.

627. Theory of Games. *Prerequisite: Math. 451 and 513 or permission of the instructor.* I. *(3).*
Extended form of a game, normal form of a game, 2-player games, minimax theorem, n-player games, linear programming, convex sets and convex cones, linear inequalities, games with infinitely many strategies.

628. Nonlinear Optimization. *Prerequisite: Linear algebra or advanced calculus.* II. *(3).*
Classification of optimization; selected topics from nonlinear, dynamic, integer, and stochastic programming with emphasis divided between theory and computer algorithms.

643. Mathematical Theory of the Mechanics of a Compressible Fluid. *Prerequisite: Math. 450 and permission of instructor.* I. *(3).*
Equations of motion, continuity, and energy for a compressible fluid; thermodynamics; theory of discontinuities (shocks, weak shocks, and characteristics); the method of characteristics for two- and three-dimensional flows; simple waves; other degenerate flows.

653. Tensor Analysis. *(3).*
Definition of tensors; tests for tensor character; manifolds; geodesics; absolute derivatives, covariant and contravariant derivatives; the curvature tensor; relative tensors; Cartesian tensors; applications to mechanics, elasticity, hydrodynamics, heat conduction, electricity, and magnetism.

656. Advanced Partial Differential Equations. *Prerequisites: Math. 558, 601 and 603 or permission of instructor.* *(3).*
Modern developments in the theory of partial differential equations.

658. Ordinary Differential Equations. *Prerequisite: Math. 602. (3).*
Existence theorems, linear systems, Sturm-Liouville theory.

748. Mathematical Theory of Elasticity. *Prerequisite: Math. 441, 442, 450 or 451.* II. *(3).*
Stress, strain; stress-strain relations; generalized plane stress; small deflection of thin plates, including circular plates, rectangular plates, and the effect of forces in the middle plane of the plate; shells of revolution under symmetrical or unsymmetrical loading.

749. Theory of the Laplace Transform. *Prerequisite: Math. 601 and 603.* I. *(3).*
Advanced topics in the theory of the Laplace transform.

751. 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. 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. Topics in Partial Differential Equations. *(3).*
Selected topics in partial differential equations.

756. Nonlinear Differential Equations. *Prerequisite: Math. 601. (3).*
Systems of ordinary differential equations, existence and general properties of solutions. Two-dimensional problems: Bendison's theorems, nature of singular points. Nonlinear springs, nonlinear electric circuits; general theory of nonlinear systems from a physical point of view, stability theory.

757. Special Functions in Classical Analysis. *Prerequisite: permission of instructor.* I. *(3).*
Gamma, Bessel, Legendre, hypergeometric, and elliptic functions. Polynomials of Legendre, Hermite, Laguerre, and Jacobi. The Sheffer classification and Sister Celine's technique.

773. Advanced Topics in Numerical Analysis. *Prerequisite: Math. 571 and 572.* II. *(3).*
Detailed study of selected topics in numerical analysis. Numerical solution of partial differential equations will be the most frequent topic. Other topics include computational problems of linear algebra, approximation theory and use of functional analysis in numerical analysis.

Mechanical Engineering

Department Office: 225 West Engineering

251. Control of Mechanical Properties of Solids. *Prerequisite: Chem.-Met. Eng. 250 and preceded or accompanied by Eng. Mech. 210 or Eng. Mech. 310.* I, II, and III*a*. *(3).*
Fundamentals of strengthening mechanisms in solids. Control of mechanical properties through control of microstructure. Use of ferrous and nonferrous alloy systems and other solids to emphasize the application of basic principles. Influence of service conditions on properties. Two recitations and one two-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. *Prerequisite: Physics 145 and Math. 215.* I and II. *(3).*
Basic thermodynamics, first law, second law, properties of a pure substance, ideal gases, and gaseous mixtures. Application to heat-power cycles. 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. 316 and 273.* 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).*
Instrumentation for experimental dynamic analysis; transducers, instrument systems and their performance; introduction and use of the analog computer; vibration theory, linear systems; comprehensive problems. Three one-hour periods and one three-hour laboratory.

343. Mechanical Design. *Prerequisite: Eng. Mech. 343, and 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.

344. Mechanical Analysis Laboratory. *Prerequisite: accompanied by Mech. Eng. 343. Not open to undergraduate mechanical engineering students.* I and II. *(1).*
Study of dynamic characteristics of various mechanical systems. Instrumentation used includes double beam cathode ray oscilloscopes, potentiometers, transformers, solar cells, photo-tubes, strain gages and other electro-mechanical transducers.

362. Mechanical Design I. *Prerequisite: Eng. Mech. 210 or 310, Mech. Eng. 251, preceded or accompanied by Mech. Eng. 381.* I, II and III*a*. *(3).*
Application of the fundamentals of engineering mechanics, materials, and manufacturing to the analysis and design of mechanical elements and systems.

381. Manufacturing Processes. *Prerequisite: Mech. Eng. 251.* I, II and III*a*. *(4).*
Correlations between microstructures, material properties, and the manufacturing processes. Design specifications of dimensional accuracy, surface finish, and material properties that are economically obtainable. Functional characteristics of processing equipment. Three recitations and one two-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.

421. Dynamics and Thermodynamics of Compressible Flow. *Prerequisite: Mech. Eng. 336 and 471.* I and II. *(3).*
Review of basic equations of fluid mechanics and thermodynamics in control volume form, one dimensional, compressible flow involving area change, normal shocks, friction, heat transfer, and combined effects. Two dimensional supersonic flow including linearization, method of characteristics, and oblique shocks. One dimensional, constant area, unsteady flow.

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 turbo-machinery.

432. Combusiton. *Prerequisite: Mech. Eng. 336, preceded or accompanied by Mech. Eng. 471 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.

436. Direct Energy Conversion. *Prerequisite: Mech. Eng. 336 or equivalent.* I. *(3).*
Thermodynamic and operational analysis of direct energy conversion devices. Topics include fuel cells, thermoelectric generators and coolers, thermionic, photovoltaic, and magnetohydrodynamic converters; demonstration of selected devices.

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.

441. Kinematic Analysis and Synthesis. *Prerequisite: Eng. Mech. 343 and Math. 273.* I. *(3).*
Vector analysis of plane and space mechanisms. Kinematic analysis of sliding and rolling contact with applications to gears, cams, and chain drives. The Grubler criterion of constraint. The Euler-Savary equation with the Hartmann and Bobillier constructions. Curvature theory including the cubic of stationary curvature. Graphic, analytical, and computer methods of synthesis.

450. Rheology and Fracture. *Prerequisite: Mech. Eng. 251.* I and II. *(3).*
Mechanisms of deformation, cohesion, and fracture of matter. Unified approach to the atomic-scale origins of plastic, viscous, viscoelastic, elastic, and anelastic behavior. The influences of time and temperature on behavior. Stress field of edge and screw dislocations, dislocation interactions, and cross slip. Surface stress and energy states, wetting, solid adhesion, friction. Ductile, creep, brittle and fatigue failure mechanisms.

460. Mechanical Design IIa. *Prerequisite: Mech. Eng. 340 and 362.* I, II, III*a*. *(3).*
An engineering design project covering the whole range of the design process from concept through analysis to layout and report with emphasis on the structure and dynamics of mechanical systems. Lectures cover the morphology of design and topics pertinent to the assigned problem. Two four-hour design periods.

461. Automatic Control. *Prerequisite: Mech. Eng. 340.* I and II. *(3).*
Linear feed-back control theory with emphasis on mechanical systems. Transient and frequency response. Stability criteria. Systems performance compensation methods. Analysis of hydraulic, pneumatic, inertial components and systems.

462. Mechanical Design IIb. *Prerequisite: Mech. Eng. 324, 362, and preceded or accompanied by Mech. Eng. 471.* II. *(3).*
An engineering design project covering the whole range of the design process from concept through analysis to layout and report with emphasis on thermal-fluid systems. Lectures cover the morphology of design and topics pertinent to the assigned problem. Two four-hour design periods.

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. Theory of Lubrication. *Prerequisite: Mech. Eng. 324.* I. *(3).*
Modes of lubrication, physical chemistry and rheology of lubricants, hydrostatic and hydrodynamic lubrication in journal and thrust bearings, including gas bearings, thin film hydrodynamic and boundary lubrication, dry friction, grease lubrication, lubrication of rolling surfaces, bearing materials.

471. Transport of Heat and Mass. *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; 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.

482. Machining Processes. *Prerequisite: Mech. Eng. 381.* I and II. *(4).*
Application of engineering fundamentals to design and analysis of machining operations. Special consideration is given to those facets of machine tool, cutting tool, and work material behavior which must be controlled in the use of computers, new electrical processes, and other modern and future facilities and techniques in manufacturing. Two recitations and two three-hour laboratories.

483(Ind. Eng. 483). Numerical Control of Manufacturing Processes. *Prerequisite: Ind. Eng. 473 or Mech. Eng. 482 and permission of instructor.* II. *(3).*
Basic elements of numerical control of metal processing systems: development of programming languages for point to point and contouring machines; interaction between geometry and machinability decisions. Laboratory experiments in optimizing part programming and equipment utilization. Two one-hour lectures and one two-hour laboratory.

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.

490. 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 term, 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.

492. Design of Heating and Air Conditioning Systems. *Prerequisite: Mech. Eng. 336.* I. *(4).*
Theory and practice considerations in the design of air, steam and water heating systems and air conditioning systems. Layout drawings of heating and air conditioning systems are made by the student. Three one-hour lectures and one three-hour design period.

496. Internal-Combustion Engines I. *Prerequisite: Mech. Eng. 336.* I and II. *(3).*
Comparison of characteristics and performance of several forms of internal-combustion engines including the Otto and Diesel types of piston engines and

the several types of gas turbines; 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 compatability. Problems of performance and economy.

501 to 513, inclusive.
These courses are offered at University of Michigan Centers outside 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 Campus. 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. 572; 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.

521. Fluid Mechanics. *Prerequisite: Mech. Eng. 324.* II. *(3).*
Principal concepts and methods of fluid mechanics. Special types of flow; methods of solution; applications to fluid machinery, fluidics, lubrication, propulsion systems and process industries.

528. Molecular Gasdynamics. *Prerequisite: Mech. Eng. 324 or permission of instructor.* I. *(3).*
Introduction to fluid flows from the molecular point of view. Molecular models and equilibrium kinetic theory of gases, classification of density regimes and discussion of free molecule flows. Gas-surface interactions. Heat transfer in rarefied gases. Fundamentals of non-equilibrium kinetic theory with application to low density flows and vacuum technology.

531. Statistical Thermodynamics. *Prerequisite: Mech. Eng. 331 or 336, Math. 316.* 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, equations 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. Va-

por 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 analog solutions.

550. Dislocations and Strength. *Prerequisite: Mech. Eng. 450 or permission of instructor.* I. *(3).*
Dislocation theory and the atomic mechanisms involved in plastic deformation of solids. Behavior of single crystals and polycrystalline solids. Theoretical description and practical observation of dislocations. Dislocation line energy, forces between dislocations, dislocation sources, stacking faults, partial dislocations, networks, image forces. Influence of dislocations on the strength of real solids.

551. Fracture of Solids. *Prerequisite: Mech. Eng. 450 or permission of instructor.* II. *(3).*
Fundamental mechanisms and modes of fracture of solids. Shear, fibrous, and ductile fracture. Cleavage, Griffith theory, and brittle fracture. Griffith-Orowan theory and quasi-brittle materials. Dislocation mechanisms involved in crack initiation. Cottrell-Hull and other models for fatigue. Recovery processes, creep deformation, creep fracture.

552. Plastic Forming of Metals. *Prerequisite: Mech. Eng. 450 or permission of instructor.* I. *(3).*
Theoretical and experimental studies of various metal-forming processes. Elastic and plastic stress-strain relationships; yielding criteria; effect of strain hardening.

553. Friction and Wear. *Prerequisite: Mech. Eng. 450 or permission of instructor.* II. *(3).*
The nature of solid surfaces, contact between solid surfaces, rolling friction, sliding friction, and surface heating due to sliding; wear and other types of surface attrition are considered with reference to practical combinations of sliding materials, effect of absorbed gases, surface contaminants and other lubricants on friction, adhesion, and wear; tire and brake performance.

556. Stress-Strain-Strength Considerations in Design. *Prerequisite: Mech. Eng. 343 or 362, or permission of the instructor.* I and II. *(3).*
A broad treatment of stress, strain, and strength with reference to engineering design and analysis. Major emphasis is placed on the analytical and experimental determination of stresses in relationship to the fatigue strength properties of machine and structural components. Also considered are deflection, post-yield behavior, residual stresses, temperature and corrosion effects.

562. Dynamic Behavior of Thermal - Fluid Systems. *Prerequisite: Mech. Eng. 461 and 471.* II. *(3).*
Principles of transport processes and automatic control. Techniques for dynamic analysis; dynamic behavior of lumped- and distributed- parameter systems, nonlinear systems and time-varying systems; measurement of response; plant dynamics. Experimental demonstration for dynamic behavior and feedback control of several thermal and fluid systems.

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.

564. Computer Aided Design Methods. *Prerequisite: Math. 473 or permission of instructor.* I. *(3).*
Currently important methods and techniques for using the computer to aid the design process. Simulation and optimization methods applied to the design of physical systems. Languages, data structures, and general hardware and software considerations: multi-programming, multi-processing and time-sharing systems.

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.

568. Design of Engineering Experiments. *Prerequisite: Mech. Eng. 343 or 362 or equivalent.* II. *(3).*
Design of experiments and interpretation of test data; reliability of measurements, experiments of exploration, evaluation and comparison; experiments to determine the effect of design changes, relationship between variables, and to establish optimum design; parametric and non-parametric tests; statistical tools.

571. Conduction Heat Transfer. *Prerequisite: Mech. Eng. 471 and Math. 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.

572. Laminar Transport of Momentum, Heat and Mass. *Prerequisite: Mech. Eng. 324 and 471.* I and II. *(3).*
Formulation of fundamental laws for continuum fluids in laminar motion. Rate of deformation fields, constitutive equations, viscous dissipation. Solution of velocity, pressure, temperature and concentration fields in steady and unsteady internal and boundary layer flows. Skin friction, heat and mass transfer coefficients. Phase change, natural convection.

573. Radiative Transport of Heat. *Prerequisite: Mech. Eng. 471.* I. *(3).*
Thermal radiation process. Physics of monochromatic 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.

581. Plastic Forming of Metals II. *Prerequisite: Mech. Eng. 552.* II. *(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.

582. Machinability Theory. *Prerequisite: Mech. Eng. 482.* 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.

589. Electrical Machining. *Prerequisite: Mech. Eng. 482 or permission of instructor.* I. *(3).*
Electromechanical machining, electrolytic grinding, electrodischarge machining, and ultrasonic removal processes are considered. Fundamental principles of process and tool design are developed in support of typical industrial applications. Unique advantages are emphasized. Lectures, problems, and discussion of current technical papers are taken up in three one-hour periods per week.

594. Internal-Combustion Engines II. *Prerequisite: Mech. Eng. 496.* II. *(3).*
Balancing of engines, advanced thermodynamic analysis of engines; chemical equilibrium, theory and control of combustion knock; combustion and air pollution problems; principles underlying recent advances in power development systems.

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; a maximum of six credit hours will be allowed toward graduate degrees).*
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 term. Course grade will be reported only as "Satisfactory".

607. Mechanical Engineering Problems. *Prerequisite: preceded by Math. 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.

631. Molecular Energy Transfer in Gases. *Prerequisite: Mech. Eng. 531 or permission of instructor.* I. *(3).*
Formulation of the transport coefficients of gases based on kinetic theory; evaluation of various intermolecular potential functions, and calculation of transport properties of pure gases and mixtures. Theoretical and experimental aspects of energy transfer during atomic and molecular collisions; relaxation phenomena; introduction to chemical kinetics.

642. Simulation of Mechanical Systems. *Prerequisite: Mech. Eng. 540.* II. *(3).*
Analysis, synthesis, and optimization of linear, multilinear, and nonlinear mechanical systems with the electronic analog computer.

671. Thermoelasticity. *Prerequisite: Mech. Eng. 556, Eng. Mech. 412, and Mech. Eng. 571.* II. *(3).*
Integral, differential and variational formulation of thermoelasticity problems including inertia and coupling effects. Extension of formulation to inelastic media. Reduction of formulation by Airy, Goodier, Love-Galerkin and Boussinesq-Papkovich functions. Application to beams, plates, two-dimensional and axially

symmetric three-dimensional problems. Various methods of exact and approximate solutions including separation of variables, transform calculus and variational calculus.

672. Turbulent Transport of Momentum, Heat, and Mass. *Prerequisite: Mech. Eng. 572 or permission of instructor.* II. *(3).*
Introduction to laminar flow stability. Statistical and phenomenological theories of turbulence. Turbulent transport of momentum, heat, and mass in steady and unsteady internal, boundary layer, and free flows. Skin friction, heat and mass transfer coefficients. Discussion of experimental results.

690. Vehicle Dynamics. *Prerequisite: Mech. Eng. 540.* I. *(3).*
A study of the transient behavior, steady-state response, and stability of automotive vehicles; suspension system dynamics; kinematics and dynamics of steering systems; theories of tire behavior; braking and cornering; aerodynamics of body styles.

700. Professional Problem. 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 this course. Letter from staff member who will direct work must accompany proposal.

772. Special Topics in Laminar Transport of Momentum and Heat. *Prerequisite: Mech. Eng. 572 and 671.* II. *(3).*
Thermal problems associated with visco-elasto-plastic fluids and solids; electromagnetic and radiation effects.

820. Fluid Mechanics Seminar. *Prerequisite: graduate standing and permission of instructor.* I or II. *(to be arranged).*
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).*
P-V-T behavior of pure substances and mixtures; chemical and phase equilibrium; electrochemistry and fuel cells; nonequilibrium thermodynamics; thermoelectricity; special topics.

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.

850. Rheology and Fracture Seminar. *Prerequisite: graduate standing and permission of instructor.* I or II. *(To be arranged).*
Selected topics for study and discussion relating atomic mechanisms to mechanical behavior of materials.

990. Doctoral Thesis. *Prerequisite: permission of thesis committee.* I and II. *(To be arranged).*
Dissertation for the degree Doctor of Philosophy supervised by the candidate's doctoral committee.

Meteorology and Oceanography

Department Office: 2038 East Engineering

202. Weather and Climate. I and II. *(3). Not open to meteorology majors.*
Elementary description of the atmosphere: its motion systems, thermal charac-

teristics, clouds and precipitation; weather map interpretation and analysis; climates of the United States.

203. The Oceans. II. *(3).*
Elementary descriptions of the oceans, their characteristics, and behavior; the sea as a world resource and as an influence on civilizations.

304. Atmospheric and Oceanic Sciences I. *Prerequisite: Physics 145.* I. *(3).*
The various aspects of meteorology and oceanography. Emphasis is placed on the geophysical and geochemical origins, composition, structure, and motions of the atmosphere and oceans.

305. Atmospheric and Oceanic Sciences II. *Prerequisite: Meteor.-Ocean. 304.* II. *(3).*
A continuation of Meteor.-Ocean. 304, with emphasis on the description and physical basis of geophysical fluid wave motions, and other physical and biological processes, introducing the student to various aspects of aeronomy, meteorology and oceanography.

306. Laboratory in Geophysical Data I. *Prerequisite: preceded or accompanied by Meteor.-Ocean. 304.* I. *(2).*
An introduction to atmospheric and oceanic data, and their practical treatment; exercises in the analysis of geophysical data in space and time; methods of observation of different elements.

307. Laboratory in Geophysical Data II. *Prerequisite: Meteor.-Ocean. 306 and preceded or accompanied by Meteor.-Ocean. 305.* II. *(1).*
Analysis of meteorological and oceanographic data, measurements of currents and winds, vertical distributions of different elements in the oceans and atmospheres, data analysis in aeronomy.

312. Physical Climatology. *Prerequisite: Meteor.-Ocean. 305 and 307.* II. *(3).*
The physical basis of climates in terms of the long-term equilibria of the earth-atmosphere system; the distribution of temperature and of circulation patterns; the role of the atmospheric water; climatic classification schemes; climatic change. Lectures, problems and discussion.

331. Atmospheric Heat and Thermodynamics. *Prerequisite: Physics 146 and preceeded or accompanied by Math. 316.* I. *(3).*
The atmosphere as a heat engine; the equation of state; dry adiabatic processes; stability; thermodynamic functions; phase changes of water; saturated adiabatic processes; thermodynamic charts; thermodynamics of radiation; solar and terrestrial radiation; terrestrial heat distribution and transfer.

332. Radiative Processes in the Atmosphere. *Prerequisite: Meteor.-Ocean. 305, Physics 146, Math. 215.* II. *(3).*
The nature of radiation, solar and terrestrial radiation, scattering, atmospheric visibility, satellite measurements of solar and terrestrial radiation.

350(Nav. Arch. 350). Ocean Engineering. *Prerequisite: Eng. Mech. 324.* II. *(3).*
A descriptive course intended to familiarize naval architecture students with relevant aspects of oceanography and oceanography students with basic naval architecture, and to introduce students in both disciplines to the evolving field of ocean engineering. Pertinent physical, chemical, biological, and geological properties of the oceans, basic naval architecture and engineering analysis of research platforms and vehicles, oceanographic instrumentation, physical oceanography, underwater acoustics, and other selected topics.

351. Geophysical Fluid Dynamics. *Prerequisite: Math. 316, Physics 145, Chem. 265 or equivalent.* I. *(3).*
Dynamics and thermodynamics of the oceans and atmosphere. Equations of motion for a rotating system; thermodynamics; kinematic principles; vorticity; geostrophic flow.

407. Methods in Climatology. *Prerequisite: Math. 465; preceded or accompanied by Meteor.-Ocean. 312.* I. *(3).*
The analysis and interpretation of climatological data; data sources; statistical methods of analysis; industrial applications of climatological information. Lectures and computations.

411. Cloud and Precipitation Processes. *Prerequisite: Meteor.-Ocean. 331 and 351.* I. *(3).*
The special nature of water substance; nucleation of phase changes in the free atmosphere; the structure and content of clouds; the development of physical characteristics of precipitation; air cleansing by rain; rain chemistry; and the dynamics of raining systems.

413. Atmospheric Electricity. *Prerequisite: Meteor.-Ocean. 411, Elec. Eng. 314 and 315.* II. *(2).*
Atmospheric ions and charging mechanisms; fair weather electric field; stormy electric fields; air conductivity and transfer of charge; charge separation; role of air dynamics; the lightning discharge and its effects upon precipitation processes; sferics.

417(Geol. 417). Geology of the Great Lakes. *Prerequisite: permission of the instructor.* I. *(3).*
Geologic history of the late-glacial and post-glacial Great Lakes of North America, with emphasis on evaluation of evidence. Related topics such as bedrock setting, engineering problems, and physical environment of sedimentation.

422. Micrometeorology I. *Prerequisite: Physics 146 or Math. 215 or permission of instructor.* I. *(3).*
Physical processes responsible for the thermal and moisture conditions in the air layer near the ground. Components of net radiation exchange, heat transfer in soil, wind structure and turbulence near the ground, turbulent transfer of sensible heat and water vapor, evapotranspiration; forest climatology, transitional microclimates.

442. Oceanic Dynamics I. *Prerequisite: Meteor.-Ocean. 351.* II. *(4).*
Wave motions; group velocity and dispersion. Gravity waves, wave statistics and prediction methods; long period waves; the tides. Steady state circulation, including theories of boundary currents and the thermocline.

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.

449. Marine Geology. *Prerequisite: permission of instructor.* I. *(4).*
Topography, geomorphology, sediments, processes and environments of the oceans; characteristics of oceanic segments of the earth's crust; theories of structural development.

451. Atmospheric Dynamics I. *Prerequisite: Meteor.-Ocean. 351.* II. *(4).*
Principles of subjective and objective analysis of atmospheric data; wave motion in the atmosphere; gravity-, inertia- and Rossby-waves; scale analysis;

quasi-geostrophic equations; simple atmospheric models for numerical prediction; calculations of vertical velocity and horizontal divergence.

454. Laboratory in Weather Analysis. *Prerequisite: preceded or accompanied by Meteor.-Ocean. 451.* II. *(3).*
Analysis of selected weather situations; calculations of vorticity, divergence, vertical velocity and advection terms; analysis of the three-dimensional structure of fronts and atmospheric waves; discussions of numerical forecasts.

462. Meteorological Instrumentation. *Prerequisite: Meteor.-Ocean. 331 or 332 or equivalent.* I. *(3).*
Principles of meteorological instruments; methods of measurement of ground level pressure, temperature, humidity, precipitation, wind, and radiation; methods of measurement of upper air conditions. Elementary analysis of response characteristics of single instruments and of instrument systems. Lectures, laboratory and field trips.

463. 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.

464(Aero. Eng. 464). Aeronomy I. *Prerequisite: senior or graduate standing.* I. *(3).*
An introduction to the physical processes in the upper atmosphere. The structure of the upper atmosphere; density, temperature, composition, and winds. Accoustical propagation and visible phenomena; the ionosphere. The physical basis of the techniques of satellite meteorology: solar, terrestrial, and atmospheric radiation processes including transfer and heat balance.

465(Aero. Eng. 465). Aeronomy II. *Prerequisite: Meteor.-Ocean. 461.* II. *(3).*
High altitude observations of aeronomical and meteorological phenomena. The physical basis and need for aerodynamic, mass spectrometric and radiative experiments. Sensor characteristics. Current balloon, aircraft, rocket, and satellite techniques.

478. Marine Chemistry I. *Prerequisite: Chem. 265.* I. *(3).*
Chemical properties of sea water and equilibria with carbonate, silicate, and other sedimentary materials and with the atmosphere. Discussion of global distribution of marine sediments, formation of manganese nodules, determination of paleotemperatures by oxygen isotopes, and the long-term history of sea water.

479. Atmospheric Chemistry I. *Prerequisite: Chem. 265.* II. *(3).*
Chemical properties of atmospheric gases and suspended particles. Discussion of the origin of the earth's atmosphere, reactions of trace gases, chemistry of precipitation, and properties of air pollutants.

481. Probability and Statistics in Forecasting. *Prerequisite: permission of instructor.* III*a*. *(3).*
The meaning of probability and its significance in weather forecasting; the value and verification of categorical and probabilistic forecasts; introduction to decision theory; statistical techniques for forecast development; the interface between statistics and dynamics in weather forecasting.

482. Physical Processes in the Atmosphere. *Prerequisite: permission of instructor.* III*b*. *(3).*
Cloud and precipitation processes, electrical effects; radiative processes involving solar and terrestrial radiation, radiation measurements from satellites.

483. Atmospheric Dynamics and Numerical Weather Prediction. *Prerequisite: permission of instructor.* III. *(4).*
A study of the basic principles of atmospheric dynamics; wave motion in the atmosphere; filtering approximations; design of dynamic models of the atmosphere; barotropic and baroclinic models; models based on the primitive equations; cloud and precipitation forecasting; numerical studies of smaller scale systems and of the general circulation.

484. Laboratory in Meteorological Analysis. *Prerequisite: permission of instructor.* III. *(2).*
Vorticity, divergence, and vertical velocity fields as determined by graphical and numerical techniques. Use of dynamics principles based on these concepts to selected weather situations.

485. Seminar in Meteorology. *Prerequisite: permission of instructor.* III. *(1).*
Reading and seminar discussion of selected fundamental problems in meteorology and related sciences. Special emphasis on problems related to operational meteorology.

522. Micrometeorology II. *Prerequisite: Math. 316, Physics 146 or permission of instructor.* II. *(3).*
Turbulent transfer processes for heat mass and momentum in the air layer near the ground; similarity principles, statistical characterization of turbulence, forced and free convection; turbulent transfer over water waves; evaporation, diffusion, advection.

531(Zool. 531). Marine Ecology. *Prerequisite: graduate standing in a science or permission of instructor.* II. *(4).*
Interactions of biological, chemical, geological, and physical factors in the marine environment. Designed to show and analyze the complex interrelationships occurring in the aquatic environment, especially as these are reflected by the biological economy.

542. Oceanic Dynamics II. *Prerequisite: Meteor.-Ocean. 442 or permission of instructor.* I. *(3).*
Circulation in the world ocean; interaction of the oceans and atmosphere; boundary currents, the thermocline, equatorial currents; the thermohaline circulation.

551. Atmospheric Dynamics II. *Prerequisite: Meteor.-Ocean. 451.* I. *(3).*
Influence of topography and heat sources on atmospheric flow, barotropic and baroclinic instability theories; energetics of the atmosphere; special aspects of the dynamics of the troposphere and the stratosphere; general circulation experiments.

564(Aero. Eng. 564). The Stratosphere and Mesosphere. *Prerequisite: Meteor.-Ocean. 464 or permission of instructor.* I. *(3).*
The physical, chemical and dynamical properties of the atmosphere between the tropopause and the turbopause. Among the topics covered are the heat and radiation budgets, atmospheric ozone, stratospheric warmings, the biennial stratospheric oscillation, airglow.

565(Aero. Eng. 565). Planetary Atmospheres. *Prerequisite: Meteor.-Ocean. 464 or permission of instructor.* II. *(3).*
The composition, structure and dynamics of extraterrestrial atmospheres; origin and evolution of planetary atmospheres; detailed treatment of the atmospheres of Mars and Venus; theoretical and empirical results, including planetary observations by space probes.

566. Design and Response of Meteorological Instruments. *Prerequisite: Meteor.-Ocean. 462 or permission of instructor.* II. *(3).*
Electric circuits used in meteorological instruments. Experimental and theoretical analysis of the response of first order sensors and recorders, (thermometers; cup, and hot wire anemometers) to square wave and sine wave imputs. Similar analysis of second order sensors (wind vanes, pressure-plate anemometers). Exercises in selection of best systems for recording most meteorological variables, lectures and laboratory.

595(Elec. Eng. 595). Topics in Space Research. *Prerequisite: permission of instructor. (3).*
Significant processes in the ionosphere and upper atmosphere (e.g. ionization, dissociation, diffusion, etc.). Solar electromagnetic and corpuscular radiation. Formation of the ionosphere; heating mechanisms in the upper atmosphere; trapped particles; interplanetary plasma; atmospheres of the planets. Measurement techniques and results of recent sounding rocket and satellite experiments.

605. Current Topics in Meteorology and Oceanography. *Prerequisite: permission of instructor.* I and II. *(3).*
Advances in specific fields of atmospheric and oceanic sciences, as revealed by recent research. Lectures, discussion, and assigned reading.

606. Computer Applications to Geo-Fluids Problems. *Prerequisite: Meteor.-Ocean. 443 or 451; Math. 273, 450. (4).*
Solution of geo-fluid problems by numerical techniques using a digital computer. Lectures, laboratory, exercises using the digital computer.

607. Statistical Methods in Meteorology. *Prerequisite: Math. 465 or 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 solution of problems on desk calculators and on digital computers.

623. Atmospheric Turbulence and Diffusion. *Prerequisite: Math. 466 or equivalent and Meteor.-Ocean. 351 or permission of instructor.* I. *(3).*
Statistical characteristics of continuous random functions and fields; microstructure and macrostructure of atmospheric turbulence; concentration distribution of conservative, passive additives; diffusion models.

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.

678. Atmospheric and Marine Chemistry II. *Prerequisite: Meteor.-Ocean. 478 and 479 or permission of instructor.* I. *(3).*
Intensive study of areas of current research interest stressing chemical processes occurring at interfaces between gas, liquid, and solid.

679. Nuclear Geochemistry. *Prerequisite: Chem. 555.* II. *(3).*
Properties of radioactive materials in the atmosphere, oceans, solid earth, and meteorites. Application to geochronology and studies of circulation and to the long-term history of the earth as a planet.

701. Special Problems in Meteorology and Oceanography. *Prerequisite: permission of instructor.* I and II. *(To be arranged).*
Supervised analysis of selected problems in various areas of meteorology and oceanography.

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

Department Office: 450 West Engineering

200. Introduction to Practice. *Prerequisite: Eng. Graphics 101.* I and II. *(3).*
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 and machinery arrangements.

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 Machinery I. *Prerequisite: Mech. Eng. 335, preceded or accompanied by Eng. Mech. 324.* II. *(3).*
The principles of design and operation of the ship's boilers, turbines, and other major machinery items.

331. Marine Machinery II. *Prerequisite: Nav. Arch. 330, preceded or accompanied by Elec. Eng. 314 and 315.* I. *(3).*
The principles of design of piping systems; electrical distribution; engine-room and deck auxiliaries.

350(Meteor.-Ocean. 350). Ocean Engineering. *Prerequisite: Eng. Mech. 324.* II. *(3).*
A descriptive course intended to familiarize naval architecture students with relevant aspects of oceanography and oceanography students with basic naval architecture, and to introduce students in both disciplines to the evolving field of ocean engineering. Pertinent physical, chemical, biological, and geological properties of the oceans, basic naval architecture and engineering analysis of research platforms and vehicles, oceanographic instrumentation, physical oceanography, underwater acoustics, and other selected topics.

400. Maritime Engineering Management. *Prerequisite: junior standing.* I and II. *(2).*
Engineering economics in ship design and operation. Shipbuilding cost estimates, contracts, specifications, and production planning. Network analysis applied to shipbuilding and ship operation.

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 and II. *(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, Eng. *Mech. 324.* I and II. *(4).*
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. Three recitations and one three hour laboratory.

430. Design of Marine Power Plants I. *Prerequisite: preceded or accompanied by Mech. Eng. 336 and Mech. Eng. 471.* I and II. *(3).*
Propulsion machinery design problems; application of steam turbines and internal combustion engines.

431. Design of Marine Power Plants II. *Prerequisite: Nav. Arch. 430.* I and II. *(3).*
Propulsion machinery design problems; piping systems; auxiliaries.

440. Ship Dynamics. *Prerequisite: Nav. Arch. 201, Eng. Mech. 343.* I. *(3).*
The motion of ships at sea: rolling, pitching, seakeeping qualities; steering and maneuvering.

446. Theory of Ship Vibrations I. *Prerequisite: Eng. Mech. 343 and Math. 214 or 316.* I and II. *(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, II, and III*a*. *(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, II, and III*a*. *(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 III. *Prerequisite: Nav. Arch. 431.* I and II. *(3).*
Complete preliminary design of ship machinery plant.

490. Directed Study, Research, and Special Problems. I and II. *(To be arranged).*
Individual study or research.

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).*

525. Naval Hydrodynamics I. *Prerequisite: Eng. Mech. 422 and Math. 450.* II. *(3).*
Wave-resistance based on linearized potential theory. Methods of evaluating wave-resistance. Application of theory to hull design. Boundary layer theory and viscous resistance.

526. Naval Hydrodynamics II. *Prerequisite: Nav. Arch. 525.* I. *(3).*
Motion of ships in calm water and waves. Forces on stationary bodies in waves and on bodies moving at constant speed. Statistical analysis of ship motion.

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.

571. Advanced Ship 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. Master's Thesis. *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 and II. *(2).*
Fundamentals of circulation theory of screw-propeller design; propeller cavitation; supercavitating propellers.

625. Naval Hydrodynamics III. *Prerequisite: Nav. Arch. 526, Math. 552.* I and II. *(To be arranged).*
Advances in specific areas of naval hydrodynamics as revealed by recent research. Lectures, discussions, and assigned reading.

630. Nuclear Ship Propulsion. *Prerequisite: Nuc. Eng. 400 or 411 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.

900. Doctoral Thesis. I and II.*(To be arranged).*

Nuclear Engineering

Department Office: 300 Automotive Engineering Laboratory

311(301). Elements of Nuclear Engineering I. *Prerequisite: Physics 146, preceded or accompanied by Math. 404.* I. *(3).*
Static properties of matter. States of matter, including the plasma state, microscopic particle distributions and elements of kinetic theory. Structure of matter. Properties of the electron, atoms, nuclei, and nucleons. Special relativity and introduction to quantum theory.

312(302). Elements of Nuclear Engineering II. *Prerequisite: Nuc. Eng. 311.* II. *(3).*
Dynamics of matter. The notion of cross sections, reaction rates, lifetimes, etc. Interaction of charged particles with electromagnetic radiation. Interaction of charged particles with charged particles. Radioactivity. Nuclear reactions, including fission and fusion.

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 power plant systems are the principal topics surveyed.

411(470). Introduction to Nuclear Engineering. *Prerequisite: preceded or accompanied by Math. 450.* I, II, and III*a*. *(3).*
A treatment of those aspects of atomic and nuclear physics prerequisite to an understanding of neutron processes. Not open to students who have taken Nuc. Eng. 311 and Nuc. Eng. 312.

415(460). Radiation Detection and Nuclear Measurements I. *Prerequisite: Nuc. Eng. 312, preceded or accompanied by course in electronics such as Elec. Eng. 337 or Phys. 455.* I. *(4).*
An introduction to the use of the common devices, techniques, and instrumentation of interest in nuclear radiation detection. Included are topics in radiation interactions, attenuation and shielding, pulse height analysis, nuclear radiation spectroscopy, and coincidence techniques. Lectures and laboratory.

416(461). Radiation Detection and Nuclear Measurements II. *Prerequisite: Nuc. Eng. 415.* II. *(4).*
Projects concerning the application of radiation detection principles in advanced measurements and instrumentation systems. Emphasis is placed on current developments in nuclear radiation spectroscopy and pulse instrumentation. Lectures and laboratory.

421. Nuclear Engineering Materials. *Prerequisite: Nuc. Eng. 312.* I. *(3).*
An introduction to materials for nuclear fuels, nuclear reactors, and nuclear radiation detection, including radiation effects in these materials by neutrons, charged particles, and gamma radiations.

425. Applied Nuclear Radiation. *Prerequisite: Nuc. Eng. 415.* II. *(4).*
Technical applications of radioisotopes and nuclear radiation. Interaction of radiation with matter, including transmission and scattering of radiation as well as an introduction to radiation effects. Lectures and laboratory.

441(430). Fission Reactors and Powerplants I. *Prerequisite: Nuc. Eng. 312.* I. *(3).*
A study of nuclear fission reactor theory and power plant design. Diffusion theory treatment of one-speed reactor core model, including reactivity and kinetic effects. Thermodynamics and heat transfer in powerplant cycles and analysis of temperature effects upon the governing parameters of solid- and liquid-moderated reactors.

442(431). Fission Reactors and Powerplants II. *Prerequisite: Nuc. Eng. 441.* II. *(3).*
A continued study of nuclear fission reactors (following Nuc. Eng. 441), including more advanced topics in one-group diffusion theory, such as self-shielding, burnable poisons, and lattice problems. Two-group and multigroup theory, including computer codes; slowing-down theory (Fermi-age), engineering aspects of powerplant systems, space applications.

445. Nuclear Reactor Laboratory. *Prerequisite: Nuc. Eng. 441 and Nuc. Eng. 415.* II and III*a*. *(4).*
Measurements of nuclear reactor performance; activation methods, rod worth, critical loading, power and flux distributions, void and temperature coefficients of reactivity, xenon transient, diffusion length, pulsed neutrons.

462. Reactor Safety Analysis. *Prerequisite: Nuc. Eng. 441 or equivalent.* I. *(3).*
Analysis of those design and operational features of nuclear reactor systems that are relevant to safety. Reactor siting, reactor containment, engineered safeguards, transient behavior and accident analysis for representative reactor types. AEC regulations and procedures. Typical reactor hazards analysis reports are discussed and analyzed.

471(420). Controlled Fusion and Plasmas. *Prerequisite: Nuc. Eng. 312.* II. *(3).*
Introduction to the requirements and operation of fusion systems. Reaction cross sections. Plasmas and plasma containment. Wave phenomena in plasmas.

Analysis of simple laboratory plasmas and devices, including glow discharges, probes, and simple pinches.

490(500). Special Topics in Nuclear Engineering I. *Prerequisite: permission of instructor.* I and II. *(To be arranged).*
Selected topics offered at the senior or first year graduate level. The subject matter may change from term to term.

499. Research in Nuclear Engineering. *Prerequisite: permission of instructor. (1-3).*
Individual or group research in a field of interest to the student under the direction of a faculty member of the Nuclear Engineering Department.

511(570). Quantum Mechanics in Neutron-Nuclear Reactions. *Prerequisite: Nuc. Eng. 312 or 411 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.

512(670). Interaction of Radiation and Matter. *Prerequisite: Nuc. Eng. 511.* 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.

545. Neutron Laboratory. *Prerequisite: Nuc. Eng. 441, Nuc. Eng. 415.* I. *(4).*
Measurements in the area of neutron physics relevant to reactor technology. The course is a project laboratory; specific experiments are agreed upon by the instructor and students.

551(641). Nuclear Reactor Instrumentation and Control. *Prerequisite: preceded or accompanied by Nuc. Eng. 441, 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.

554(750). Radiation Shielding. *Prerequiste: Nuc. Eng. 415, preceded or accompanied by Nuc. Eng. 512.* II. *(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.

555(640). Application of the Analog Computer in Nuclear Engineering. *Prerequisite: preceded or accompanied by Nuc. Eng. 441 or preceded by Nuc. Eng. 400.* I. *(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.

561(730). Nuclear Power Plant Engineering II. *Prerequisite: Nuc. Eng. 441 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.

562(731). Nuclear Power Plant Engineering III. *Prerequisite: Nuc. Eng. 561 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.

565(631). Nuclear Power Plant Laboratory. *Prerequisite: preceded or accompanied by Nuc. Eng. 441, 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.

590(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 term to term.

599(690). Master's Project. *(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 term by mutual agreement between the student and staff member. The student will write a final report and may be required to make a seminar presentation.

611(770). Theory of Nuclear Reactions I. *Prerequisite: Nuc. Eng. 512.* 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.

612(771). Theory of Nuclear Reactions II. *Prerequisite: Nuc. Eng. 611.* II. *(3).*
Study of neutron-nuclear reactions with some attention to medium effects, charged-particle nuclear reactions, and beta decay. Developments of neutron balance relations incorporating appropriate neutron-nuclear cross sections.

621(751). Radiation Effects in Solids. *Prerequisite: Nuc. Eng. 512.* I. *(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.

622(752). Selected Topics in Radiation Effects. *Prerequisite: Nuc. Eng. 621.* 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.

643(780). Nuclear Reactor Theory II. *Prerequisite: Nuc. Eng. 441 and Math. 552 or 557 or Phys. 452.* I. *(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.

644(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.

671(720). Thermonuclear Theory I. *Prerequisite: Nuc. Eng. 441.* 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.

672. (721). Thermonuclear Theory II. *Prerequisite: Nuc. Eng. 671.* 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.

771. Plasma Instabilities in Controlled Fusion I. *Prerequisite: Nuc. Eng. 672 or permission of instructor.* I. *(3).*
Study of the stability of fully ionized gases in magnetic fields with applications to controlled thermonuclear fusion. Linear theory of plasma oscillation; the energy method and hydromagnetic instability; finite Larmor radius stabilization of plasma and related topics.

772. Plasma Instabilities in Controlled Fusion II. *Prerequisite: Nuc. Eng. 771.* II. *(3).*
Continuation of Nuc. Eng. 771. Plasma microinstabilities; velocity-space and drift instabilities; convective and absolute instabilities; quasi-linear theory of plasma oscillation and plasma turbulence.

799(991). Special Projects. *(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 term by mutual agreement between the student and a staff member.

840(880). Seminar in Nuclear 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.

999. Doctoral Thesis. *(1-6).*

Physics*

Department Office: 1049 Randall

Professor Crane; Professors Case, Dennison, Ford, Franken, Hazen, Hecht, Jones, Katz, Krimm, Laporte, Lewis, McCormick, Meyer, Parkinson, Peters, Ross, Sanders, Sands, Sherman, Sinclair, Terwilliger, Weinreich, Wiedenbeck; Associate Professors Coffin, Hendel, Janecke, Krisch, Longo, Overseth, Roe, Tickle, VanderVelde, Ward, Worthington, Wu, Zorn; Assistant Professors Bardwick, Chapman, Gould, Gray, Kane, Mani, Murphy, Reidy, Rich, Robiscoe, Springett, Tomozawa, Williams, Yao.

* College of Literature, Science, and the Arts.

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. 316 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. 316.* I and II. *(3).*
The level of sophistication is between the levels of Physics 305 and Physics 453.

401. Intermediate Mechanics. *Prerequisite: Physics 126 or 146 and Math. 316 or equivalent.* I and II. *(3).*
Study of the motion of single particles, systems of particles, and rigid bodies. Harmonic oscillators, coupled oscillators, rockets; central force laws including planetary motion, Rutherford scattering and perturbed orbits using center-of-mass co-ordinates; rotating co-ordinate systems, Coriolis force. Introduction to Lagrange's equations.

402. Light. *Prerequisite: Physics 126 or 146 and Math. 316 or equivalent.* I. *(3).*
The phenomena of physical optics, reflection, refraction, dispersion, interference, diffraction, polarization, etc., interpreted in terms of the wave theory of light.

405. Intermediate Electricity and Magnetism. *Prerequisite: Physics 126 or 146 and Math. 316 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. 316 or equivalent.* II. *(3).*
Fundamental physical facts and concepts, thermodynamic variables, equations of state. The zeroth, first, second, and third law of thermodynamics and their mathematical consequences; the concepts of internal energy, enthalpy, entropy, functions of Helmholtz and of Gibbs. Thermodynamics of irreversible processes. Applications to various branches of physics, e.g., magnetic cooling, thermoelectricity, etc.

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 used to treat several classical problems. The student is introduced to elementary aspects of turbulence, shock waves, and hydromagnetics.

417. Physical Techniques in Biophysics. *Prerequisite: Physics 126 or 146.* I. *(3).*
A survey of the physical techniques used to study the ultrastructure of biological materials. An elementary treatment of microscopy and diffraction methods using light, electrons, and X-rays; light scattering and spectroscopy.

418. Introduction of Physics of Macromolecules. *Prerequisite: Math. 214 and Physics 402 or permission of instructor.* II. *(3).*
A discussion of methods of structure determination and a survey of our knowledge of the physical structures of macromolecules and the principles underlying their formation. This is followed by an introduction to theories which relate structure to physical properties. Emphasis is placed on biological systems where possible.

425. Introduction to Infrared Spectra. *Prerequisite: Physics 126 or 146 and Math. 214.* I. *(2).*
A discussion of the elements of vibrational spectroscopy, both infrared and Raman, followed by a survey of their application to the study of the structure and internal force fields of molecules, both simple and complex.

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 term will be advanced classical physics (particle dynamics, Maxwell equations, hydrodynamics, and kinetic theory). The second term 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. *(3 each).*
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 Nuclear Physics I. *Prerequisite: Physics 401, Physics 405, or five hours of physical chemistry.* I and II. *(3).*
Presentation of some concepts of quantum mechanics; theory of the simpler atoms, molecules and nuclei in terms of the Schroedinger equation. Discussions of fundamental experiments and of current research in atomic physics.

455. Electron Tubes. *Prerequisite: Physics 405.* 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. Atomic and Nuclear Physics II. *Prerequisite: Physics 453.* I and II. *(3).*
Further developments of quantum theory, such as symmetry properties and scattering theory, applied to the more complex atoms and nuclei; discussion of current research in nuclear and elementary particle physics. Given as a sequence with Physics 453.

458. Methods and Apparatus of Nuclear and Elementary Particle Experimental Physics. *Prerequisite: Physics 401, 405.* I. *(2).*
A discussion of the experimental devices and techniques of nuclear and particle physics including ionoptic and particle beams, accelerators, and detectors.

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 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. *(2).*
The two laws and their foundation; gas equilibria 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 term. 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

Office: 4211 East Engineering

The following courses have been developed through interdepartmental co-operation. The 300 and higher level courses are 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 descriptions.

101. Engineering Concepts and Perspective. *Prerequisite: high school algebra, trigonometry, chemistry, and physics.* I and II. *(3).*
A study of engineering concepts and solution of a wide variety of problems to give perspective, orientation, and foundation for engineering study and practice. Two lectures, two problem solving periods.

110. Computer Graphics. I and II. *(4).*
Introduction to computer-augmented design philosophy; geometric construction; principles of drafting and projections; analysis and synthesis of a drawing; dimensioned and scaled drawings in 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. 316.* II. *(4).*
A unified study of heat, mass, and momentum transfer and chemical kinetics, with emphasis on description, measurement, correlation, and process design.

490. Research and Special Problems. *Prerequisite: permission of instructor.* **I,** II, III*a*, and III*b*. *(To be arranged).*
Work on research projects, design or analysis problems, or economic studies carried out by special arrangement under the direction of an individual faculty member, with approval of the program adviser.

Committees and Faculty*

Executive Committee†

Dean G. J. Van Wylen, *Chairman*
ex officio

C. Kikuchi, term, 1964-68
W. L. Root, term, 1965-69
J. R. Pearson, term, 1966-70
E. E. Hucke, term, 1967-71

Standing Committee†

Dean G. J. Van Wylen, *Chairman,* H. B. Benford, J. A. Clark, J. W. Daily, J. G. Eisley, H. W. Farris, G. V. Edmonson, W. M. Hancock, A. R. Hellwarth, E. E. Hucke, H. T. Jenkins, W. Kerr, C. Kikuchi, W. C. Nelson, J. R. Pearson, F. E. Richart, J. E. Rowe, W. L. Root, T. M. Sawyer, Jr., N. R. Scott, L. H. Van Vlack, and A. C. Wiin-Nielsen.

Committee on Classification

A. W. Lipphart, *Chairman,* W. C. Holcombe, and C. W. McMullen.

Committee on Scholastic Standing

R. C. Porter, *Chairman,* K. Chuang, W. R. Debler, D. C. Douglas, P. R. Klaver, E. J. Lesher, R. A. Loomis, E. A. Martin, R. A. Martin, W. Mirsky, R. F. Mosher, G. Parravano, W. S. Rumman, T. Y. Tien, J. W. Winchester.

Committee on Discipline

E. F. Brater, *Chairman,* H. H. Alvord, A. R. Hellwarth, and R. F. Mosher.

Committee on Scholarships and Loans

R. E. Carroll, *Chairman,* H. Bradley, J. D. Goddard, R. B. Harris, A. R. Hellwarth, N. R. Scott, J. E. Shigley, and C. Yeh.

Committee on Curriculum†

F. H. Westervelt, *Chairman,* J. G. Eisley, F. C. Michelsen, C. B. Sharpe, and J. O. Wilkes.

* Listed for the academic year 1967-68.
† By arrangement, this committee meets with representatives of the student body appointed by the Engineering Student Council.

Committee on Combined Courses with College of Literature, Science, and the Arts

W. C. Bigelow, *Chairman,* R. B. Harris, and A. R. Hellwarth.

Committee on Freshman Counseling†

C. W. Johnson, *Chairman,* W. J. Anderson, H. R. Colby, J. D. Goddard, R. O. Goetz, A. R. Hellwarth, R. H. Hoisington, A. W. Lipphart, A. F. Nagy, N. R. Scott, C. A. Siebert, R. A. Volz, and G. L. West, Jr.

Committee on Placement†

S. K. Clark, *Chairman,* J. Akerman, H. Benford, H. Buning, G. C. Gill, F. G. Hammitt, R. B. Harris, C. W. Johnson, L. F. Kazda, G. B. Williams, and J. G. Young.

Committee on Program Counseling†

A. R. Hellwarth, *Chairman,* all undergraduate program advisers.

Aerospace Engineering

Wilbur Clifton Nelson, M.S.E., *Professor of Aerospace Engineering and Chairman of the Department of Aerospace Engineering*
Thomas Charles Adamson, Jr., Ph.D., *Professor of Aerospace Engineering*
Frederick Joseph Beutler, Ph.D., *Professor of Information and Control Engineering, Department of Aerospace Engineering*
Harm Buning, M.S.E., *Professor of Aerospace Engineering*
Joe Griffin Eisley, Ph.D., *Professor of Aerospace Engineering and Associate Dean of the College of Engineering*
Elmer Grant Gilbert, Ph.D., *Professor of Information and Control Engineering, Department of Aerospace Engineering*
Donald Theodore Greenwood, Ph.D., *Professor of Aerospace Engineering*
Robert Milton Howe, Ph.D., *Professor of Aerospace Engineering*
Leslie McLaury Jones, B.S.E. (E.E.), *Professor of Aerospace Engineering*
Arnold Martin Kuethe, Ph.D., *Felix Pawlowski Professor of Aerodynamics*
Edgar James Lesher, M.S.E., *Professor of Aerospace Engineering*
Vi-Cheng Liu, Ph.D., *Professor of Aerospace Engineering*
James Arthur Nicholls, Ph.D., *Professor of Aerospace Engineering*
Rudi Siong-Bwee Ong, Ph.D., *Professor of Aerospace Engineering*
Lawrence Lee Rauch, Ph.D., *Professor of Information and Control Engineering, Department of Aerospace Engineering*
William Lucas Root, Ph.D., *Professor of Aerospace Engineering*
William Walter Willmarth, Ph.D., *Professor of Aerospace Engineering*
Frederick Lester William Bartman, Ph.D., *Associate Professor of Aerospace Engineering*
Arthur Frederick Messiter, Jr., Ph.D., *Associate Professor of Aerospace Engineering*
Pauline Mont Sherman, M.S., *Associate Professor of Aerospace Engineering*
Martin Sichel, Ph.D., *Associate Professor of Aerospace Engineering*

† By arrangement, this committee meets with representatives of the student body appointed by the Engineering Student Council.

William Judson Anderson, Ph.D., *Assistant Professor of Aerospace Engineering*
Stuart Wayne Bowen, Ph.D., *Assistant Professor of Aerospace Engineering*
Tyrone Edward Duncan, Ph.D., *Assistant Professor of Information and Control Engineering, Department of Aerospace Engineering*
Nathaniel Harris McClamroch, Ph.D., *Assistant Professor of Information and Control Engineering, Department of Aerospace Engineering*
Richard L. Phillips, Ph.D., *Assistant Professor of Aerospace Engineering*
David L. Sikarskie, D.Sc.Eng., *Assistant Professor of Aerospace Engineering*
Laurence Eugene Fogarty, Ph.D., *Lecturer in Aerospace Engineering and Research Engineer, Sponsored Research*

Chemical and Metallurgical Engineering

Lawrence H. Van Vlack, Ph.D., *Professor of Materials Engineering and Chairman of the Department of Chemical and Metallurgical Engineering*
Donald LaVerne Katz, Ph.D., *Alfred H. White Distinguished Professor of Chemical Engineering and Associate Chairman of the Department of Chemical Engineering*
Richard Earl Balzhiser, Ph.D., *Professor of Chemical 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*
J. Donald Hanawalt, Ph.D., *Visiting Professor of Metallurgical Engineering*
Edward Ernest Hucke, Sc.D., *Professor of Metallurgical Engineering*
Lloyd L. Kempe, Ph.D., *Professor of Chemical Engineering and Microbiology, Medical School*
Joseph J. Martin, D.Sc., *Professor of Chemical and Metallurgical Engineering*
Giusseppe Parravano, Ph.D., *Professor of Chemical and Metallurgical Engineering*
John E. Powers, Ph.D., *Professor of Chemical Engineering*
Clarence Arnold Siebert, Ph.D., *Professor of Chemical and Metallurgical Engineering*
Maurice Joseph Sinnott, Sc.D., *Professor of Metallurgical Engineering*
Mehmet Rasin Tek, Ph.D., *Professor of Chemical Engineering*
George Brymer Williams, Ph.D., *Professor of Chemical and Metallurgical Engineering*
Jesse Louis York, Ph.D., *Professor of Chemical and Metallurgical Engineering*
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 Schneidewind, Ph.D., *Professor Emeritus of Metallurgical Engineering*
Lars Thomassen, Ph.D., *Professor Emeritus of Chemical and Metallurgical Engineering*
Rane L. Curl, Sc.D., *Associate Professor of Chemical Engineering*
William F. Hosford, Jr., Ph.D., *Associate Professor of Metallurgical Engineering*
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Robert Donald Pehlke, Sc.D., *Associate Professor of Metallurgical Engineering*
Jerome S. Schultz, Ph.D., *Associate Professor of Chemical Engineering*
Tseng-Ying Tien, Ph.D., *Associate Professor of Materials Engineering*
James Oscroft Wilkes, Ph.D., *Associate Professor of Chemical Engineering*
Richard Emory Townsend, Ch.E., *Associate Professor Emeritus of Chemical and Metallurgical Engineering*
Robert E. Barry, Ph.D., *Assistant Professor of Chemical Engineering*
Brice Carnahan, Ph.D., *Assistant Professor of Chemical Engineering and Biostatistics, Medical School*
Francis M. Donahue, Ph.D., *Assistant Professor of Chemical and Metallurgical Engineering*
Hugh Scott Fogler, Ph.D., *Assistant Professor of Chemical and Metallurgical Engineering*
Joe Dean Goddard, Ph.D., *Assistant Professor of Chemical Engineering*
Orville Fred Kimball, Ph.D., *Assistant Professor of Materials Engineering*
Nicholas W. Prodany, Ph.D., *Assistant Professor of Chemical Engineering*
William Allen Spindler, M.S., *Assistant Professor of Metallurgical Engineering*
Gregory S. Y. Yeh, Ph.D., *Assistant Professor of Materials Engineering*
Walter Bertram Pierce, *Assistant Professor Emeritus of Foundry Practice*
Dale Edward Briggs, M.S.E., *Instructor in Chemical and Metallurgical Engineering*

Civil Engineering

Frank Edwin Richart, Jr., Ph.D., *Professor of Civil Engineering and Chairman of the Department 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*
Robert Blynn Harris, M.S.C.E., *Professor of Civil Engineering and Associate Chairman, 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*
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*

Glenn Leslie Alt, C.E., *Professor Emeritus 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*
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F. Benjamin Wylie, Ph.D., *Associate Professor of Civil Engineering*
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Charles P. Powers, Ph.D., *Assistant Professor of Sanitary Engineering, Department of Civil Engineering.*
Richard D. Woods, Ph.D., *Assistant Professor of Civil Engineering*
George Moyer Bleekman, M.S.E., *Assistant Professor Emeritus of Geodesy and Surveying*
Larry L. Kole, M.S.E., *Lecturer in Civil Engineering*
Ward Karcher Parr, B.S.E. (Ch.E.), *Lecturer in Civil Engineering*
Bruce Douglas Greenshields, Ph.D., *Lecturer Emeritus in Transportation Engineering, Department of Civil Engineering, and Assistant Director Emeritus of the Transportation Institute*
John M. Armstrong, M.S., *Instructor in Civil Engineering*

Electrical Engineering

Hansford White Farris, Ph.D., *Professor of Electrical Engineering and Chairman of the Department of Electrical Engineering (Fall Term 1967).*
Joseph Everett Rowe, Ph.D., *Professor of Electrical Engineering and Chairman of the Department of Electrical Engineering (Winter Term 1968).*
Ben Frederick Barton, Ph.D., *Professor of Electrical Engineering*

Richard Kemp Brown, Ph.D., *Professor of Electrical Engineering*
William Milton Brown, Dr.Eng., *Professor of Electrical Engineering*
John Joseph Carey, M.S., *Professor of Electrical Engineering*
Chiao-Min Chu, Ph.D., *Professor of Electrical Engineering*
Louis John Cutrona, 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*
Arlen R. Hellwarth, M.S., *Professor of Electrical Engineering and Associate Dean and Secretary of the College of Engineering*
Ralph E. Hiatt, M.S., *Professor of Electrical Engineering*
Gunnar Hok, E.E., *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*
Raymond Fred Mosher, S.M., *Professor of Electrical Engineering*
James Carlisle Mouzon, Ph.D., Sc.D., *Professor of Electrical Engineering*
Andrejs Olte, Ph.D., *Professor of Electrical Engineering*
Norman Ross Scott, Ph.D., *Professor of Electrical Engineering and Associate Dean of the College of Engineering*
Charles Bruce Sharpe, Ph.D., *Professor of Electrical Engineering*
Newbern Smith, Ph.D., *Professor of Electrical Engineering*
Chen-To Tai, Ph.D., *Professor of Electrical Engineering*
Herschel Weil, Ph.D., *Professor of Electrical Engineering*
Chai Yeh, D.Sc., *Professor of Electrical Engineering*
Hempstead Stratton Bull, M.S., *Professor Emeritus of Electrical Engineering*
William Gould Dow, M.S.E., *Professor Emeritus of Electrical Engineering*
Lewis Nelson Holland, M.S., *Professor Emeritus of Electrical Engineering*
Edwin Richard Martin, E.E., *Professor Emeritus of Electrical Engineering*
Arthur Dearth Moore, M.S., *Professor Emeritus of Electrical Engineering*
Melville Bigham Stout, M.S., *Professor Emeritus of Electrical Engineering*
Theodore G. Birdsall, Ph.D., *Associate Professor of Electrical Engineering*
Thomas W. Butler, Jr., Ph.D., *Associate Professor of Electrical Engineering*
Donald Albert Calahan, 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*
Ward Douglas Getty, Ph.D., *Associate Professor of Electrical Engineering*
George I. Haddad, Ph.D., *Associate* Professor *of Electrical Engineering*
Keki Burjorji Irani, Ph.D., *Associate Professor of Electrical Engineering*
Eugene L. Lawler, Ph.D., *Associate Professor of Electrical Engineering*
Emmett Norman Leith, M.S., *Associate Professor of Electrical Engineering*
Ronald J. Lomax, Ph.D., *Associate Professor of Electrical Engineering*

Edward Anthony Martin, Ph.D., *Associate Professor of Electrical Engineering*
Edward Lawrence McMahon, Ph.D., *Associate Professor of Electrical Engineering*
Murray Henri Miller, Ph.D., *Associate Professor of Electrical Engineering*
Andrew F. Nagy, Ph.D., *Associate Professor of Electrical Engineering*
Arch W. Naylor, Ph.D., *Associate Professor of Electrical Engineering*
Anthony James Pennington, Ph.D., *Associate Professor of Electrical Engineering*
William A. Porter, Ph.D., *Associate Professor of Electrical Engineering*
Spencer Leigh BeMent, Ph.D., *Assistant Professor of Electrical Engineering*
Peter J. Khan, Ph.D., *Assistant Professor of Electrical Engineering*
William N. Lawrence, Ph.D., *Assistant Professor of Electrical Engineering*
John Frederick Meyer, Ph.D., *Assistant Professor of Electrical Engineering*
Marlin P. Ristenbatt, Ph.D., *Assistant Professor of Electrical Engineering*
Richard A. Volz, Ph.D., *Assistant Professor of Electrical Engineering*
William J. Williams, Ph.D., *Assistant Professor of Electrical Engineering*
Eric M. Aupperle, M.S., *Lecturer in Electrical Engineering*
Norman E. Barnett, M.S. (Phys.), *Lecturer in Electrical Engineering and Associate Research Physicist, Sponsored Research*
George R. Carignan, B.S., *Lecturer in Electrical Engineering and Research Engineer, Sponsored Research*
Harold C. Early, M.S., *Lecturer in Electrical Engineering and Research Engineer, Sponsored Research*
Ernest G. Fontheim, Ph.D., *Lecturer in Electrical Engineering*
Raymond F. Goodrich, Ph.D., *Lecturer in Electrical Engineering*
Ralph E. Kleinman, Ph.D., *Lecturer in Electrical Engineering*
William B. Ribbens, Ph.D., *Lecturer in Electrical Engineering*
Thomas B. A. Senior, Ph.D., *Lecturer in Electrical Engineering*
Vincent A. Vis, Ph.D., *Lecturer in Electrical Engineering and Research Engineer, Sponsored Research*
Vaughan H. Weston, Ph.D., *Lecturer in Electrical Engineering*

English

Thomas Mitchell Sawyer, Jr., 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*
George Middleton McEwen, Ph.D., *Professor of English, College of Engineering*
Edward M. Shafter, Jr., Ph.D., *Professor of English, College of Engineering*
Stephen Sadler Stanton, Ph.D., *Professor of English, College of Engineering*

Robert P. Weeks, Ph.D., *Professor of English, College of Engineering*
Ivan Henry Walton, A.M., *Professor Emeritus of English, College of Engineering*
Chester Fisher Chapin, Ph.D., *Associate Professor of English, College of Engineering*
Warne Conwell Holcombe, Ph.D., *Associate Professor of English, College of Engineering*
Ralph A. Loomis, Ph.D., *Associate Professor of English, College of Engineering*
Richard John Ross, Ph.D., *Associate Professor of English, College of Engineering*
Richard Emerson Young, Ph.D., *Associate Professor of English, College of Engineering*
William Byrom Dickens, Ph.D., *Associate Professor Emeritus of English, College of Engineering*
William Henry Egly, A.M., *Associate Professor Emeritus of English, College of Engineering*
Alton Lewis Becker, Ph.D., *Assistant Professor of English, College of Engineering*
Arthur Willard Forbes, A.M., *Assistant Professor of English, College of Engineering*
Leonard A. Greenbaum, Ph.D., *Assistant Professor of English, College of Engineering, and Assistant Director, and Editor, Phoenix Publications, Phoenix Project*
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Roger Milliken Jones, M.A., *Assistant Professor of English, College of Engineering*
Peter Roberts Klaver, Ph.D., *Assistant Professor of English, College of Engineering*
Chester Raymond Leach, Ph.D., *Assistant Professor of English, College of Engineering*
Robert Allen Martin, Ph.D., *Assistant Professor of English, College of Engineering*
John Charles Mathes, Ph.D., *Assistant Professor of English, College of Engineering*
Linda Martha Nevins, Ph.D., *Assistant Professor of English, College of Engineering*
Rudolf B. Schmerl, Ph.D., *Assistant Professor of English, College of Engineering*
Dwight Ward Stevenson, Ph.D., *Assistant Professor of English, College of Engineering*
W. Harry Mack, A.M., *Assistant Professor Emeritus of English, College of Engineering*
Hubert Irwin Cohen, M.A., *Instructor in English, College of Engineering*
Thomas C. Edwards, A.M., *Instructor in English, College of Engineering*
David Marlin Heaton, M.A., *Instructor in English, College of Engineering*
Peter N. Heydon, M.A., *Instructor in English, College of Engineering*
David Bruce Spaan, 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*
Robert Seaton Heppinstall, M.S.(M.E.), *Professor of Engineering Graphics*
Alfred William Lipphart, B.S.E.(Ae.E.), LL.B., *Professor of Engineering Graphics and Assistant to the Dean of the College of Engineering*
Frank Harold Smith, M.S.E., *Professor of Engineering Graphics*
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*
Philip Orland Potts, M.S.E., *Professor Emeritus of Engineering Graphics*
Donald Craig Douglas, B.S.M.E., *Associate Professor Engineering Graphics*
Robert Horace Hoisington, M.S., *Associate Professor of Engineering Graphics and Assistant Dean of the College of Engineering*
Kurt Christian Binder, B.S.E.(M.E.), M.B.A., *Assistant Professor of Engineering Graphics*
Raymond Clare Scott, M.S.(Ed.), *Assistant Professor of Engineering Graphics*
Francis X. Lake, Ph.D., *Assistant Professor Emeritus of Engineering Graphics*
Philip Edward Webb, M.S.E., *Instructor in Engineering Graphics*

Engineering Mechanics

James Wallace Daily, Ph.D., *Professor of Engineering Mechanics and Chairman of the Department of Engineering Mechanics*
Samuel Kelly Clark, Ph.D., *Professor of Engineering Mechanics*
John Hermann Enns, Ph.D., *Professor of Engineering Mechanics*
William Paul Graebel, Ph.D., *Professor 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)
Hadley James Smith, Ph.D., *Professor of Engineering Mechanics*
Chia-Shun Yih, Ph.D., *Professor of Fluid Mechanics, Department of Engineering Mechanics*
Russell Alger Dodge, M.S.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*
Jesse Ormondroyd, A.B., *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*
Roger Dean Low, Ph.D., *Associate Professor of Engineering Mechanics*
Ivor Keen McIvor, Ph.D., *Associate Professor of Engineering Mechanics*
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