COLLEGE OF ENGINEERING

1971-1972

THE UNIVERSITY
OF MICHIGAN

OFFICIAL PUBLICATION

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Calendar 1971-72

Fall Term, 1971

Orientation	September 5-8, Sunday-Wednesday
Labor Day (holiday)	September 6, Sunday
Registration	September 7-8, Tuesday-Wednesday
Classes begin	September 9, Thursday
Thanksgiving recess begins (5 p.m.)	November 24, Wednesday
Classes resume (8 a.m.)	November 29, Monday
Classes end	December 13, Monday
Study days	December 14-16, Tuesday-Thursday
Examinations	December 17-23, Friday-Thursday
Winter commencement	December 19, Sunday

Winter Term, 1972

Orientation	January 9-12, Sunday-Wednesday
Registration	January 11-12, Tuesday-Wednesday
Classes begin	January 13, Thursday
Vacation begins (12 noon)	March 4, Saturday
Classes resume (8 a.m.)	March 13, Monday
Classes end	April 21, Friday
Study days	April 22, 24-25, Saturday, Monday-Tuesday
Examinations	April 26-May 2, Wednesday-Tuesday
Spring commencement	May 6, Saturday

Spring-Summer Term, 1972

Registration-Orientation	May 8-9, Monday-Tuesday
Classes begin	May 10, Wednesday
Memorial Day (holiday)	May 29, Monday
Classes end	June 28, Wednesday
Study day	June 29, Thursday
Examinations	June 30-July 1, Friday-Saturday
Spring Half Term ends	July 1, Saturday
July 4th (holiday)	July 4, Tuesday
Summer Half Term Registration	July 5-6, Wednesday-Thursday
Summer Half Term classes begin	July 7, Friday
Classes end	August 23, Wednesday
Study day	August 24, Thursday
Examinations	August 25-26, Friday-Saturday
Summer commencement	August 20, Sunday
Full Term and Summer Half Term end	August 26, Saturday

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Office Directory

General University Offices

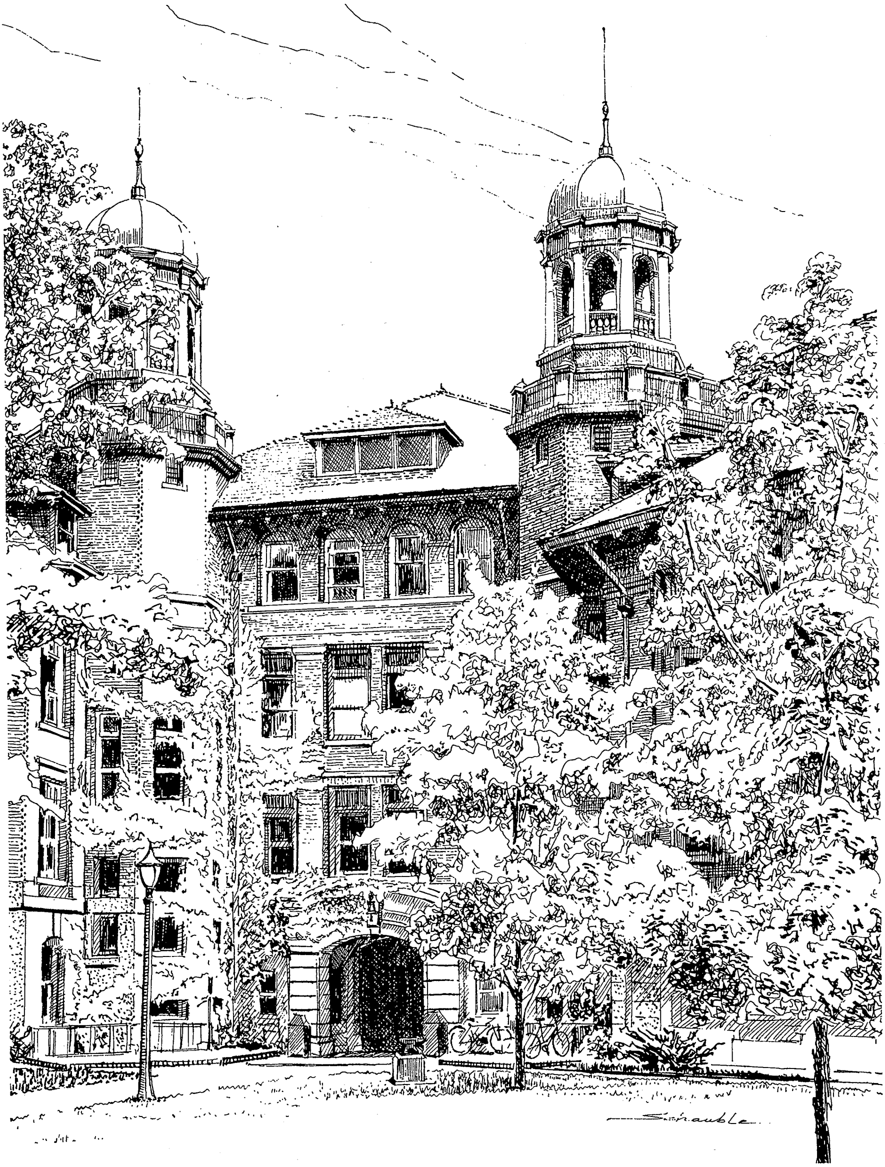
Academic Affairs, Office of, 3080 Administration
Admission of Freshmen, Student Activities Building
Automobile permits, 3011 Student Activities Building
Cashier's Office, 1015 Literature, Science, and the Arts Building (LSA) and 2226 Student Activities Building
Director of Admissions, Student Activities Building
D.O.B., 3528 LSA Building
Eligibility for Activities, Student Activities Building
Employment:
  hospital employment, A6002 Hospital
  University offices, 1020 LSA Building
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, LSA Building
Orientation, West Quad
Placement Services, 3200 Student Activities Building
President's Office, 2074 Administration
Print Lending Library, Student Activities Building
Refund of term fees, 1513 LSA Building
Residence Halls:
  Business Manager, 2244 Student Activities Building
  fees, payment of, 2226 Student Activities Building
Scholarship bulletins, Student Activities Building
Secretary of the University, 2080 Administration
Sororities, information about, 1011 Student Activities Building
Student activities, Student Activities Building
Student Affairs, Office of, Student Activities Building
Summer Half Term Office, 3564 LSA Building
Veterans Affairs, 1510 LSA 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, 248 West Engineering
  Associate Dean and Secretary A. R. Hellwarth, 259 West Engineering
  Associate Dean R. C. Wilson, 268 West Engineering
  Assistant Dean R. H. Hoisington, 259 West Engineering
  Assistant to the Dean R. E. Carroll, 273 Chrysler Center
  Assistant to the Dean H. H. Harger, 247 West Engineering
  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. R. Packard, 247A West Engineering
  Assistant to the Dean J. G. Young, 128H West Engineering
Freshman Counseling, 275 West Engineering
Lost and Found:
  2258 SAB
  Office of the Assistant Dean, 259 West Engineering
Placement, student and alumni, 128H West Engineering, J. G. Young, and department offices
Records Office, 263 West Engineering
Transcripts, 263 West Engineering
Transfer students, admission of, 259 West Engineering

Contents



COLLEGE OF ENGINEERING

Robben W. Fleming, B.A., LL.B., LL.D., *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*
Richard C. Wilson, 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.), J.D., *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*

For Committees, Departments, Chairmen, and Faculty see page 224.

General Information

Our society is increasingly dependent on a scientific and technological base not only for its prosperity but for its very survival. Throughout the modern era, the need has been great for men and women who as scientists can discover the truths of nature, or as engineers can apply those truths "for the benefit of mankind." Never has the need been greater than it is today.

Engineers as well as scientists make their contributions to the storehouse of knowledge. It should be stressed, however, that engineers are occupied primarily with solving real-life problems. Engineering is a profession that began as a practical art, and although it has become less of an art and more of a science, its main concern is still "the benefit of mankind."

By bringing to bear on each problem a proper combination of knowledge, experience, and judgment, engineers seek the best or most economical solution. Every day of every year, they find more and more ways to make our way of life easier, safer, cleaner, and more comfortable—for more and more people. They invent methods for doing something never done before. Unhappy with what exists, they are always seeking ways to improve, to do things better and more efficiently. In the various processes of inventing, designing, manufacturing, and constructing, engineers are concerned continually with the use of manpower, and the effects of their creativity on people and their total welfare. They also find ways of coping with the problems that derive from their earlier successes—such problems as air and water pollution, mass transportation, the noises of supersonic travel, or the need for better forms of information storage and retrieval.

In our time, the engineering approach to problems has taken on particular importance because social and technological problems have become so closely interrelated. The problem of air pollution, to cite but one example, cannot be solved in terms of the underlying physical causes alone. We must know why it looms as such a major problem; what social, political, legal and ethical conflicts it arouses; and how the alternative technological solutions would affect both individual and group interests or welfare. Positions in modern engineering demand a sensitivity to such problems across the full range of our social and economic concerns. The College of Engineering is dedicated to educating young men and women for such technological leadership.

To an increasing number of young people today, the words "environment" and "ecology" suggest a wide range of opportunities that lie ahead in solving the problems and meeting the needs of contemporary society. The solution to these problems certainly involves the contributions of the engineers who design, build, and operate our machines, plants, and processes.

Students in the College of Engineering have the opportunity to elect courses that will broaden their knowledge of the environment and ecology. Those who do will be particularly well qualified to utilize their technical knowledge in developing definitive solutions of environmental problems.

The College's enduring educational objective is that of preparing its students for positions of responsibility that are commensurate with their abilities and interests. But the means by which the College carries out this objective must be continually revised in the light of conditions that are continually changing in education and throughout the whole of society. Students enrolled in the College soon discover that its programs have been planned to prepare them for any one of a broad range of possibilities. According to their aptitudes and desires, the students may go on to become practicing engineers, or researchers, or administrators, or teachers. Moreover, the knowledge and discipline gained from undergraduate engineering study are proving to be excellent preparation for other careers, particularly in business, law, and medicine. Many graduates of the College remain after they have received an undergraduate degree to earn a master's or doctor's degree. Another opportunity for continued growth and development beyond the undergraduate degree is that of registration as a professional engineer. After a certain length of experience (usually four years) the young engineer can take qualifying examinations offered by the state in which he seeks registration.

At Michigan, students have an opportunity to associate with distinguished teachers who have not only solid academic grounding but also broad professional involvement, the result of continuing research and consultation on actual engineering projects. The College believes that such professional involvement is necessary if its faculty is to retain maximum efficiency both in the classroom and the laboratory. The benefits of such involvement are passed on to students through formal classroom exposure and through informal exposure as well. Often, teaching is most effective when a teacher can work together with students in fundamental scientific investigations, or on improved ways of applying scientific knowledge to the problems of industry and public well-being. Graduate and undergraduate students in the College have an opportunity to participate in such activities in well-equipped engineering laboratories and at a number of field locations.

The College's program for undergraduate study consists typically of a four-year program leading to a bachelor's degree. There are thirteen programs that lead to the degree Bachelor of Science in Engineering, and two that lead to the degree Bachelor of Science; these are identified throughout this catalog as B.S.E. and B.S., respectively. By careful planning, an additional bachelor's degree (B.S. or A.B.) can be earned in the University's College of Literature, Science, and the Arts in about one year beyond the time required for the B.S.E. and the B.S. For further information, refer to the later section on Undergraduate Programs.

Career Choice

How can a high school student determine whether or not he is qualified to be an engineer? Some of the clues might be: an interest in and successful completion of science and mathematics courses; a desire and ability to investigate the "why" as well as the "how" of things; and an interest in the creative development of devices or systems that meet specific needs. The engineer of the future will be increasingly concerned with the preservation of our natural environment, the wise use of our natural resources, and the importance of individual creativity and initiative in the framework of a free democratic society. Certainly not all of these signs or interests will fit everyone, but they can be used as a rough guide.

More and more girls are enrolling in engineering. Women who like science and mathematics will find engineering a satisfying career with a wide variety of employment opportunities. The College has one of the largest distaff enrollments of any engineering school in the country.

Officers and academic counselors within the College are glad to consult with high school or transfer students who are faced with a critical career choice or with the problem of choosing the school that best suits their interest and abilities. A student with questions in this regard may benefit from a leaflet entitled *Engineering*—available by writing to the Dean of the College.

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 1970, approximately 3300 undergraduate students (with 750 entering for first time from high school) and 960 graduate students were enrolled in engineering. The total enrollment of the University on the Ann Arbor Campus is approximately 32,000.

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

The University is located in Ann Arbor, a city of about 100,000 including students; it is located within forty miles from the heart of Detroit, and is adjacent to one of 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, Nuclear, Physics, Sanitary (first degree M.S.E.), and Science.

Facilities

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 Laboratory
- Highway Safety Research Institute Building
- 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 descriptions of the undergraduate degree programs include a reference to the facilities for the respective programs.

The **Computing Center** provides the University community with central digital computing facilities for use in the 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 360 Model 67 Duplex with its supporting Time Sharing System software permits remote real time access through a large variety of terminal devices in addition to on-line batch processing of data. Problems may be transmitted to the central machine from remote graphical cathode ray tube displays and 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 1,300 periodicals and maintains large collections of technical reports, and government documents.

The **Phoenix Library,** located in the Phoenix Memorial Laboratory on North Campus, is a divisional library of the University of Michigan General Library and is also a depository library for the United States Atomic Energy Commission.

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

Other Physical Facilities. On request, the University will provide information on its facilities for housing, health care, recreation, physical education, and athletic participation.

Work-Study Opportunities

While the College does not sponsor a formal cooperative work-study plan, it is willing to accommodate a student who wishes to combine work experience with his engineering studies. In such a plan, the student devotes alternate terms to study at the College and in some form of related employment, generally adding a year or more to his graduation date.

In some instances the employer takes the initiative by proposing the co-op program for a qualified student; in others, the student may take the first step. The College does not exercise any control over the agreement between the student and his employer.

Ordinarily, the College does not allow credit for co-op work experience. A note will be entered on the student's academic record when the student informs the Assistant Dean's Office of his plan to enroll during alternate terms.

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.

In addition, summer employment opportunities are available to a large number of students, particularly at the end of the second and third year. Many employers who recruit graduates also offer summer work to undergraduates through interviews at the campus. The college believes that such experiences are equivalent to those claimed for the formal cooperative plan and highly recommends that each student include a summer period of related employment, if possible, in his schedule.

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 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 the 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 Professional Engineers provides an opportunity for students during their senior year to take the first half of a sixteen-hour two-part examination as the first step toward registration, provided the degree is awarded within six months after the examination. This first part 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 applicant will take the second half of the examination which will involve the application of engineering judgment and planning ability.

On completing his registration, an engineer establishes his professional standing on the basis of legal requirements and receives authority to practice his profession before the public. 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 have an opportunity to participate in a number of extracurricular activities. Some of these are associated with a professional society, others with social organizations, musical and drama groups, sports, or service groups. In addition, a great many cultural programs are offered throughout the year—more than anyone could possibly attend.

The College of Engineering encourages participation in the wide range of activities—campus-wide as well as those within the College. Used to advantage, college activities can provide a basis for many friendships and memorable times, as well as an opportunity for self-development.

The following is a list of organizations of particular interest to students in Engineering. Those interested in exploring other campus-wide opportunities may obtain a complete list of campus organizations at the Office of Student Organizations, 1011 Student Activities Building.

Professional Societies

American Institute of Aeronautics and Astronautics, student chapter
American Institute of Chemical Engineers, student chapter
American Institute of Industrial Engineers, student chapter
American Nuclear Society, student chapter
American Society of Civil Engineers, student chapter
American Society of Mechanical Engineers, student chapter
American Society of Tool and Manufacturing Engineers, student chapter
Institute of Electrical and Electronics Engineers, student chapter
Michigan Metallurgical Society, student chapter
Society of Automotive Engineers, student chapter
Society of Women Engineers, student chapter

Honor Societies

The criteria for election to one of the Honor Societies are based on the rules and regulations of the respective Society. In general, the criteria include a scholastic requirement.

Student members of a society are responsible for election of new members. On request, the College will provide to each society the names and local addresses of students who are eligible for election according to scholastic criteria specified by the respective society.

Alpha Phi Mu, national industrial engineering honor society
Chi Epsilon, national civil engineering honor society
Eta Kappa Nu, national electrical engineering honor society
Pi Tau Sigma, national mechanical engineering honor fraternity
Phi Eta Sigma, national honor society for freshman men
Phi Kappa Phi, national honor society for seniors of all schools and colleges
Quarterdeck Society, honorary-technical society for the Department of Naval Architecture and Marine Engineering
Tau Beta Pi, national engineering honor society
Triangles, junior men's engineering honor society
Vulcans, senior men's engineering honor society

College Service Activities

IAESTE-US, International Association for the Exchange of Students for Technical Experience, United States, Michigan chapter
Meteorology and Oceanography Student Council, for the Department of Meteorology and Oceanography

Michigan Technic and Datum staff, publishers of the Michigan Technic—student magazine for the College, and Datum—student newspaper

Society of Black Engineers

University of Michigan Amateur Radio Club, organization of students interested in radio communications as a hobby

College Student Government and Judiciary

Engineering Council. The University of Michigan Engineering Council is the student government of the College of Engineering and serves as the representative for engineering student opinion on College and University issues. The Council's work, done by committees, advisory boards and a coordinating executive board, includes efforts in student-faculty relations, summer and permanent job placement, grades and grading and faculty and course evaluation. Membership is open to all students of the College and the sole requirement for full membership is attendance at three of four consecutive meetings. A flier detailing Council activities and organization is available in the Dean's Office, 255 West Engineering, or in the Engineering Council Office.

The Council welcomes the opinions of all students, from freshmen to seniors, as well as their active participation in its projects. New ideas and projects are always welcome. Those wishing to express opinions or to bring ideas to the Council should attend a Council Meeting or come to the Engineering Council Office, 128F West Engineering, 764-8511.

Honor Council. The Student Honor Council, the student judiciary for the College, has the responsibility of conducting hearings and recommending action in the cases of alleged violation of the Honor Code or College rules on conduct.

Scholarships, Fellowships, Prizes, Loans, and Employment

Numerous University scholarships, fellowships, and prizes, as well as loan funds, are available to qualified engineering students. 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. Very few engineering scholarships are available to incoming freshmen or transfer students. New students can apply for a scholarship during their second term of residence here, providing they have completed at least 14 credit hours with a minimum average of 2.5.

Applications for Engineering College scholarships are accepted during the periods of January 15 to February 15 and September 15 to October 15. Application forms can be obtained at the Scholarship Office, 273 Chrysler Center—North Campus or the Engineering Dean's Office, 255 West Engineering Building—Central Campus. For more information call 763-2180.

Many of our scholarship funds are made available through the generosity of alumni and other friends of the College. There is no direct obligation to repay a scholarship but as recipients recognize their moral obligation to return to the College scholarship fund according to their several abilities, other worthy students will likewise benefit.

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 (or their children) 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 or to Director of Student Certification, LSA Building.

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, or to Director of Student Certification, LSA Building.

Fee Regulations, Expenses, Indebtedness

A nonrefundable fee of $15 will be required of each applicant for admission to the University.

The fees for one full term for the 1971-72 academic year will be as follows:

	Undergraduate *10 credit hours or more*	*Graduate* *8 credit hours or more*
Michigan Resident	$ 330	$ 400
Non-resident	$1070	$1120

The following guideline may be used for the total expenses:

Michigan resident (2 terms, academic year)	$2500
Non-Michigan U.S. citizen (2 terms, academic year)	$4000
Foreign (3 terms, calendar year)	$6500

Fees are subject to change at any time by the Board of Regents of the University.

Detailed information relating to fees, deposits, payments and refunds may be obtained in the Assistant Dean's Office.

Withdrawal. A student withdrawing after registration shall pay a disenrollment fee according to the rules in effect at the time of withdrawal.

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 transcript of academic record or diploma 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 satisfy the health requirements as stated below.

In order to be assured of equal consideration with other qualified applicants, and to complete the necessary enrollment and housing arrangements, an applicant should submit his application for admission to the fall term by February 1. However, qualified Michigan applicants who seek admission after this date will be given careful consideration consistent with the ability of the University to provide adequate facilities for instruction.

Health. The first enrollment of all full- and part-time students requires Health Service approval. This is granted when the report is received of a recent medical examination, completed by a physician of the applicant's choice, upon a form provided at time of admission. It is not intended to establish physical requirements for admission, and the nature of the 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 order to best serve the student and the university community. All such information is, of course, confidential.

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.

The following requirements will be in effect for the first time fall 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

Deficiency: It is possible to be admitted with a deficiency. An applicant who has a deficiency is advised to consult the Director of Admissions concerning his particular problem. When conditions warrant such action, provisional admission may be granted if not more than two units are lacking. Courses elected at the University to remove deficiencies will not count toward degree.

2. Scholastic Performance. The student's grades—particularly in mathematics, chemistry, physics, and courses that indicate verbal ability—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 career, as well as to predict his likelihood of success in the engineering profession. See profile below.

3. Scholastic Aptitude Test. Tests in verbal and mathematical abilities have proven helpful for predicting success in engineering courses. 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 08540, or to Box 1025, Berkeley, California 94701.

4. High School Recommendation. Any statement by a representative of the applicant's high school is taken into account. This may relate to such qualities as 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 1970 freshman engineering class of approximately 750, 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.

Standing in high school class	
Rank	*% of Class*
top 10%	57%
second 10%	26%
third 10%	10%
other	7%

College Board Scholastic Aptitude Test Scores		
Range	*Mathematical*	*Verbal*
Median	659	562
700-800	29%	4%
650-699	25%	12%
600-649	29%	18%
550-599	11%	21%
500-549	4%	20%
below 500	2%	25%

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 08540, or to Box 1025, Berkeley, California 94701.

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.

While credit is not allowed for work or other experience, a student may be considered proficient in a designated part of his degree requirement if he can qualify under provision 3(e) of Requirements for Bachelor's Degree.

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

Attention of prospective transfer students is called to the section on Planning the Student's Program.

Program with Basic Courses Taken in Another Institution. Basic pre-engineering courses in mathematics, chemistry, physics and English composition or literature 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 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 cooperates 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	Eastern Michigan University
Alma College	Grand Valley State College
Andrews University	Hope College
Calvin College	Kalamazoo College
Central Michigan University	University of the South

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 details on a combined program with the College of Literature, Science, and the Arts of the University, refer to Undergraduate Degree Programs.

Admitting Graduates of Other Colleges. A graduate of an approved college may be admitted as a candidate for a degree in engineering. The official transcript must certify the date of graduation. Upon the satisfactory completion of the prescribed courses, covering at least two 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 gradepoint 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.

Prescribed Program. When an applicant is judged to be adequately qualified, he may be admitted with the understanding that when he satisfactorily completes a schedule of courses prescribed by his program adviser, he will be awarded his degree. This makes unnecessary a detailed evaluation of credit earned previously. It would apply ordinarily to a person with a bachelor's degree from another college, or equivalent, and capable of satisfying the degree requirements in the range of 30 to 40 credit hours.

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 subect 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.

Unassigned Status. When a student decides that he is no longer a candidate for a degree from the College of Engineering but is planning to transfer into another field of study, he is advised to report to the Assistant Dean who will counsel on effecting a transfer and, if necessary, arrange for registration for an additional term in the College of Engineering on an "Unassigned" status.

Foreign Students

Foreign students whose native language is other than English are required to complete basic college subjects, i.e. English, mathematics, chemistry, physics, 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.

Finances. When a foreign applicant accepts an offer of admission, he should clearly understand the financial obligations assumed. If he needs assistance, he must make the necessary arrangements before leaving his home country.

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

Each student is expected to assume a high degree of responsibility for his own welfare by making proper choices, and effectively planning his progress toward his educational goal. To do this wisely and efficiently, he should understand his own aptitudes, abilities and interests and their relationship to his plans and decisions. A student with some question in this regard, or one who recognizes he has a personal problem in which he might benefit from appropriate counseling, is urged to consult University people who are qualified to help him.

A student who experiences in his first term any difficulty in making a satisfactory adjustment to his studies should report immediately to his academic counselor. If he is uncertain regarding procedures or if he has a problem that does not relate to a specific counseling service, he may seek advice from the Assistant Dean's Office, 259 West Engineering Building.

Orientation. All new students, both freshmen and those transferring from other colleges, are assigned to small groups which are guided through the various steps of orientation; these include testing, Health Service x-ray, preparation of the student's identification card, consultation with academic counselors, selection of courses, registration, assessment of fees, and attendance at the necessary orientation group meetings.

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

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

For transfer students—some of the programs offer an opportunity to come to the campus during the summer for a two-day orientation schedule.

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 make choices, and to appraise his own performance and intellectual growth is an important part of the student's education. Neverthless, each freshman is encouraged to consult with freshman counselors or program advisers at any time he has a question relating to his career plans, or choice of academic program, or 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 each student above the freshman level on his academic program.

Certain authorities, as covered under Election of Studies, Grades and Scholastic

Standing, and Requirements for Graduation, 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 Services 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.

Minimum Common Requirements

Each of the 15 degree programs offered by the College includes the following 56 credit hours that are common to all programs, subject to appropriate adjustment for equivalent alternatives.

To be scheduled during first 4 terms as shown below.	*Hours Credit*
1) Mathematics 115, 116, 117, 215, and 216	16
2) Humanities 101 and 102 (Great Books I and II)	6
3) Engineering 101 and 102	4
4) Chemistry 103 or 104	4
5) Physics 140 and 141, and 240 and 241	8

Additional 18 hours (minimum)

6) Literature and Rhetoric (see courses under Humanities) 6
(to be scheduled during junior and senior years)
7) Humanities and Social Sciences .... 12‡
(may be scheduled any term—see Elective Studies)

Freshman and Sophomore Program

For each freshman, the counselor will use his high school record, and the results of various tests to plan the courses for his first term. A student with an admission deficiency is required to remove it during his first year.

Studies of the first year. While variations in freshman schedules are possible, the following will serve as a guide for planning:

First Term	*Hours Credit*	*Second Term*	*Hours Credit*
Mathematics 115	4	Mathematics 116	3
Humanities 101, Great Books I	3	Mathematics 117	2
Engineering 101, Graphics*	2	Humanities 102, Great Books II	3
Engineering 102, Computing*	2	Chemistry† or elective	4
Chemistry 103 or 104	4	Physics 140 with lab. 141	4

Combinations of the subjects listed above usually will result in a term schedule with 15 to 17 credit hours. The appropriate number for each student will depend on a number of factors: past scholastic record, placement tests, extracurricular activities, election of Military Officer Education Program, and need for partial self-support.

Military Officer Education Program. Opportunities are offered for officer training in military, naval, and air science leading to a commission on graduation. Enrollment is voluntary (see conditions of enrollment under the respective program). If elected the grades earned will be recorded and used in the computation of grade point averages, but credit hours will not be included with the hours completed toward the degree. On approval of the student's program adviser, a maximum of four credit hours of advanced courses (Junior and Senior courses) will be designated on the academic record as credit toward the degree requirement.

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. To help the student with his choice, the departments will schedule a series of group meetings during the winter term that provide information about each of the programs and related career opportunities. If he needs additional help, he should consult with his freshman counselor, or with the 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

‡ Several programs require more than the minimum of 12. For complete information on the requirements of the respective programs, see later section on "Undergraduate Degree Programs."
* An elective may be substituted for these 2 courses, in which case they will appear in second term schedule. Also see Variations below.
† See Chemistry under variations below.

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.

Studies for the Second Year. All students will continue with the mathematics and physics courses common to all programs marked by * in the Group I list below. A second term freshman who has selected his degree program is referred to the respective program adviser for elections counseling for his third term; for the remainder of his second-year elections, he should refer to the description of the program selected. If his program requires additional chemistry, he must continue chemistry in order to satisfy prerequisites of later courses and to avoid delays in his schedule.

When a freshman is not ready to select a degree program in his second term, it is possible to define a second year schedule on an unassigned basis. The courses marked † in Group I satisfy requirements in a number of programs or may be applied as electives in other programs. Those in Group II will be found in the second year schedule of certain programs and provide the student with an opportunity to continue his schedule with the understanding that if not used as a requirement in the program he will select, they generally may be used as electives. The student should consult the course descriptions to help him make appropriate selections. If a sophomore is ready to select his program during his third term, he will be referred to his program adviser for his fourth term elections.

Third Term	*Hours Credit*	*Fourth Term*	*Hours Credit*
Group I			
*Mathematics 215	4	*Mathematics 216 or 286	3
*Physics 240 with Lab. 241	4	†Eng. Mech. 340	4
†Eng. Mech. 211	4	or 345	3
or 218	3	†Mech. Eng. 331	4
†Mat.-Met. Eng. 250	3	or 335	3
†Humanities or Social Science	4	†Humanities or Social Science	4
Group II			
Chemistry 225	3	Chemistry 226 & 227 or 265	5 or 4
Aero. Eng. 200	2	Physics 242	3
Chem. Eng. (Mat.-Met. Eng.) 230 with Lab. 231	4	Statistics 310	3
Civ. Eng. 262	4	Civ. Eng. 312	3
Elec. Eng. 200	2	Elec. Eng. 211	2
Meteor-Ocean. 304	3	or 215	3
Meteor-Ocean. 306	2	Ind. Eng. 300, 310, or 333	3
Nav. Arch. 200	3	Mech. Eng. 251	3
		Mech. Eng. 252	2
		Meteor-Ocean. 305 and 307	4
		Nav. Arch. 201	3

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, he will find that he can accomplish this in a minimum of time by discussing his intent early with the respective program advisers. 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 Additional Bachelor's Degrees.)

Variations

The following variations and possibilities for accelerating the progress of qualified students will serve as additional guides. 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.

Mathematics. The new mathematics sequence of 115 (4), 116 (3), 117 (2), 215 (4), and 216 (3) provides an integrated sixteen-hour sequence in college mathematics that includes analytic geometry, calculus, elementary linear algebra, and elementary differential equations. The previous sequence of 115 (4), 116 (4), 215 (4), and either 216 (4) or 315 (2) and 316 (2) was phased out during the academic year 1970-71. Details concerning offerings and credit can be found in the course descriptions.

While most freshmen select Mathematics 115 in their first term, it is in the best interest of the student to be placed 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 (4) or 195 (4). See also the Unified Science sequence below.

A student who has completed a full year of calculus in high school and has received a sufficiently high score on one of the College Board Advanced Placement Examinations in mathematics is eligible for advanced credit and placement. Likewise, a student who has 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 both algebra and trigonometry	Math. 105	4*
II.	Are deficient in trigonometry	Math. 107 (May accompany Math. 115)	2*
III.	Have no deficiences 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
VI.	Are allowed 4 hours of advanced placement credit	Math. 116 and 117	5
VII.	Are allowed 7 hours of advanced placement credit	Math. 117 or Math. 117 and 215	2 or 6

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

A transfer student who has completed college algebra together with plane and solid analytic geometry without calculus and linear algebra, normally will be allowed five hours of credit and will be required to take Mathematics 117 (2), 213 (4), 214 (4), and 216 (3) to complete the minimum requirement in mathematics. Under these circumstances, two elective credit hours may be allowed for Mathematics 117 when approved by the student's program adviser.

A student choosing the program in Applied Mathematics should elect the combination of Mathematics 350 (3) and 351 (3) in place of Mathematics 216.

Humanities. The Department of Humanities offers an integrated program beginning with a year of Great Books leading to a junior literature seminar and then to a senior writing and speech seminar. The first year includes Humanities 101 (3) and 102 (3); these two courses in Great Books are intended to introduce the student to important works in literature, philosophy, and history. The work will include the writing of essays based on the reading.

Most freshmen elect 101 in the first term, but exceptionally able and well prepared students who demonstrate proficiency through written examinations administered by the Department of Humanities may have one or both of these required courses waived. A variety of humanities electives is available for students who need additional courses to complete a program in succeeding terms.

Freshmen may also receive credit on the basis of College Board Advanced Placement scores in English. A student entering with three hours Advanced Placement credit, or with an English course in freshman composition taken elsewhere, may elect either 101 or 102, and then the literature and writing seminars.

Freshmen entering with six hours advanced placement credit and transfer students who receive six hours credit for composition courses should elect Humanities 330, Great Works, and then the literature seminar only; those who receive three hours credit may elect either Humanities 101 or 102 and then both the literature and writing seminars.

Humanities 103 (3) and 104 (3) (special courses) are offered for foreign students.

For further information see the course descriptions under Humanities.

Engineering. Two credit hours of engineering graphics and two credit hours of digital computing or their equivalent are required by each program. This requirement may be met by any one of three options:

Option 1—Engineering 101, Graphics (2), and Engineering 102, Digital Computing (2); most students will be electing this option as shown in the several program schedules.

A student desiring to be excused from taking Engineering 101 because of high school drawing courses must submit evidence of his proficiency and may be required to pass an examination.

Option 2—Engineering 110, Computer Graphics, (4). This course covers essentially the same material as Engineering 101 and 102, and serves to integrate the two subjects. Enrollment is limited because of facilities. Students who have an introduction to computers and graphics in high school or through employment are likely candidates for this course.

Option 3—Engineering 120, Engineering Concepts and Computations (4) and Engineering 101, Graphics (2). Engineering 120 provides an introduction to engineering through the solution of a variety of engineering problems typical of those encountered in practice. It provides an excellent opportunity to observe the relevance of chemistry, physics, and mathematics to engineering, and is particularly desirable for a student: a) who wishes to develop his problem-solving ability by working typical engineering problems; b) who is uncertain of the field of engineering he will enter and, therefore, would like to sample a variety of engineering problems; or c) who is uncertain of his interest in engineering, and, therefore, would like to have some typical engineering problems to help with his decision.

Engineering 120 is offered only in the fall term with enrollment limited because of facilities. One half of the course satisfies the requirement of Engineering 102; the student will elect Engineering 101 in the winter term. The half of Engineering 120 devoted to engineering problems will count as two hours of elective credit.

If the College is unable to place a student in any option during the fall term, he may elect instead a humanities or social science course; in this case he will elect Option 1 in the winter term.

Chemistry. The minimum requirement in chemistry is one 4 credit hour course, which can be met by either Chemistry 103 (4), 104 (4), or 196 (honors) (5). The counselor will recommend the most appropriate course for the student's first term, based on placement examination and other information.

Since Chemistry 196 is a 5 hour course, 4 hours is credited towards the chemistry requirement and 1 hour for elective credit. A student who is eligible for Chemistry 196 may elect Chemistry 104 instead. Chemistry 196 satisfies the prerequisite for 200 level chemistry courses, which may be elected the second term; those who elect Chemistry 103 or 104 must take Chemistry 105 (4) or 106 (4) before qualifying for additional chemistry.

Any student may elect a second chemistry course in his second term. A student with chemistry 103 or 104 who plans to enter degree programs in Chemical, Materials, or Metallurgical Engineering, Meteorology and Oceanography, or Engineering Physics should elect Chemistry 105 or 106 the second term. He should refer also to the schedule of the respective program and, if in doubt, consult with the program adviser to determine the most suitable sequence of advanced chemistry.

A student with a grade of A or high B in Chemistry 104 may be invited to elect Chemistry 191 (5) instead of Chemistry 106. This combination provides the student with additional background and improves his ability to master advanced courses.

A student with advanced placement credit in chemistry will be given special counseling for his first term elections.

Physics. The usual freshman schedule includes Physics 140 (3) with laboratory, Physics 141 (1). This course assumes knowledge of calculus and is normally scheduled to follow Mathematics 115; transfer students placed in Mathematics 213 (4) may elect Physics 140 and 141 concurrently.

A second course, Physics 240 (3), with laboratory, Physics 241 (1), is required by all programs and should be scheduled in the third term. A third course Physics 242 (3) is required for the program in Electrical Engineering, and may be elected for other programs (see studies for the second year above).

Foreign Languages. Although a foreign language is an important part of the high school education, it is not required for admission nor does it appear in any program requirement. It is recognized that a number of students are admitted with the equivalent of college-level work in a language. When a student demonstrates a high proficiency by an Advanced Placement Examination (taken either at the high school or after arriving at the University) a notation will be made of his achievement on his academic record. Allowance of an appropriate amount of credit as an elective in the humanities and social science group is subject to the approval of his program adviser.

Unified Science Sequence. The Unified Science Sequence consists basically 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. The required courses are to be taken in the following order:

First Term:	Math. 185 (4 hours) and Chemistry 196 (5 hours)
Second Term:	Math. 186 (4 hours)
Third Term:	Math. 285 (4 hours) and Physics 190 (5 hours)
Fourth Term:	Math. Elective and Physics 191 Lab. (1 hour)

By integration of the subject matter and by a special emphasis on theoretical principles, these courses treat each subject in a more rigorous fashion and at a more advanced level than would otherwise be possible. They thereby provide for a superior background in science and mathematics which can be highly valuable for students in engineering.

In addition to the required courses listed above, there is the opportunity to participate in an honors biology course, as well as an honors colloquium course in the history of science. The biology course, Honors Zoology 106 (5 hours), is recommended as an elective only for those students with a strong high school background in biology who have special interests in the field. For example, this course would provide an excellent background for those who intend to pursue careers in biochemical engineering, bioengineering, or related areas.

One of the courses in the L.S.A. College honors courses 199, 293, or 295 is a possible fifth-term elective for all students in the Unified Science Sequence. These courses, which will normally involve one or more specially chosen lecturers, are intended to serve as a unifying element and focal point for the Unified Science Sequence, by tracing the historic developments in diverse areas of astronomy, physics, and natural science and philosophy which have led to the present day interdisciplinary activities in these areas.

Because of their integrated character, the courses listed above can normally be taken only in the order shown, and it is necessary for a student to enroll in them as a freshman and to complete the full two-year sequence to obtain maximum benefits 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 a special counselor, 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, and by invitation from, this counselor. 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.

A student who elects the benefits of the honors courses is not eligible for advanced placement credit except as agreed to by the special counselor.

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

The engineering profession has a long standing record of fostering high standards of integrity in the performance of professional services. Not until the 1930's however was the first Canons of Ethics for Engineers developed and adopted by national professional engineering societies. The following statement relating to ethical conduct is part of a revision of the Canons approved by Engineers' Council for Professional Development in 1963.

"The Engineer, to uphold and advance the honor and dignity of the Engineering Profession and in keeping with high standards of ethical conduct:

1. Will be honest and impartial, and will serve with devotion his employer, his clients, and the public;
2. Will strive to increase the competence and prestige of the engineering profession and;
3. Will use his knowledge and skill for the advancement of human welfare."

In 1916, about thirty years before the first Canon of Ethics was published, the students of the College of Engineering proposed an Honor Code. This was approved by the faculty and has been in effect since its inception. The Honor Code truly is a distinguishing feature of enrollment in the College of Engineering.

By observing the code, students do their work in an environment conducive to establishing high standards of personal integrity and professional ethics.

As a basic feature of the code, each student is placed upon his honor during all examinations and written quizzes for courses conducted by members of the faculty of the College of Engineering. Although the instructor makes himself available for questions, he does not proctor the examination. The student 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 which is then investigated by the Student Honor Council, resulting in a recommendation to the Faculty Committee on Discipline.

The Honor Council has prepared a booklet, available at 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.

Use of Facilities. Laboratory, classroom and office equipment, shops, the library, and the computer are examples of a wide variety of facilities that serve as aids for instruction and research. Their use is limited to the purpose for which they are made available and any misuse will be subject to disciplinary action.

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 approximately 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

In the following rules and procedures, the word "term" also applies to half term 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. See under counseling.

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 normally selects his program of study during the second term of his freshman year and is referred to the appropriate program adviser. A tentative program established at this time will be helpful as a guide to the student and his elections counseling through the completion of his degree requirements. See Freshman and Sophomore Program for exception.

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 and prerequisites), 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 Humanities and the program adviser, the student may be required to elect such further work as may be deemed necessary.

Work Load. The number of hours a student is able to carry in any one term depends upon a number of factors—including his abilities, his health, and the amount of time he devotes to extracurricular activities or to outside work. Twelve credit hours are considered a minimum full academic schedule for a full term (six for half term). Reduced program fees apply to nine credit hours or less for undergraduate students.

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.

Attention is called to the section on Time Requirements for a statement on estimating the time needed for a bachelor's degree.

Classification and Registration. As needed, the Assistant Dean's Office will prepare 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 may be cause for referral to the Discipline Committee. Late registration is subject to penalty of $15.

A student who completes the registration procedure (including early) and fails to attend classes must officially withdraw from college through the Assistant Dean's Office and pay the usual disenrollment fee.

Change of Classification. After a term has begun, adding or dropping a course can be made official only through use of "election change request" 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.

A course may be added during the first few weeks of a term with the express permission of the instructor with whom arrangements must be made for the necessary make-up work. In most cases this consideration puts a practical time limit of the first two weeks of a term (or the first week of a half term) for adding courses. Thereafter the program adviser (or the Assistant Dean, for freshmen) also must approve any addition.

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 a Military Officer Education Program must have approval also of the chairman in charge of the unit before he can drop a Military Officer Education Program 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 and appropriately reported to Assistant Dean's Office. All substitutions approved are subject to review by the Curriculum Committtee.

Electives. See guidelines under Elective Studies.

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. See Unassigned Status.

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.

Grades associated with transfer credit are not recorded nor used in computing the cumulative average.

A course elected under Pass-Fail option does not affect a student's 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. Other copies are released by the Records Office only when requested by the student except as restricted under "Indebtedness to the University."

First official copy of a student's academic record is provided without charge, and additional copies at $1.00 each.

Grade Reports. Unless withheld for infringement of rules, each term's grades are reported to the student. When a student under age 21 is not in good scholastic standing, a report is sent to 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.

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, excepting I (incomplete) and N (no report). 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).
The committee schedules interviews before the beginning of each term; to arrange an appointment at another time, write to the secretary of the Committee on Scholastic Standing at 255 West Engineering Building.

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. As soon as possible the instructor and student should mutually understand the reasons for the "I" mark and agree on methods for completing the work.

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 and graded.

The required work may be completed and the grade submitted by the instructor regardless of whether or not the student is enrolled. The student should plan to complete the work as soon as possible; however, in order that credit may be allowed, the required work must be completed by the end of the first term (not including spring-summer term) in which the student is enrolled after the term in which the "I" mark was recorded. One notice of his deadline date will be mailed to the student; if he does not meet the foregoing requirement, the "I" mark will be changed to E by the Records Office when the grades are posted at the end of the term. It is the student's responsibility to remind the instructor to send supplementary grade report to Engineering Records Office when the work is completed.

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 proper form.

The student must consult the Assistant Dean's Office on the necessary procedures for resolving such cases, if there has been an error. An N (no report) will be changed to "U" if the student takes no action to have it cleared by the end of the next term enrolled.

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. See next paragraph for exception.

For Freshman—Adjusting Cumulative Average. When a course has been repeated, for which a grade of D or E had been earned in either of the first two terms of enrollment as a freshman in the College of Engineering, only the grade and credit hours earned the last time the course has been elected are included in computing the cumulative grade point average. The course must be repeated in the next regular term that it is scheduled.

Pass-Fail Option. A student who has completed 30 hours of credit or more (including transfer credit) and is in good scholastic standing may elect courses on a pass-fail basis as follows:

1) All elective courses in the humanities and social sciences. (Courses in the uniform 12 hour requirement of Great Books, Literature and Rhetoric requirement may not be elected on a pass-fail basis).

2) a) Any combination of free electives and technical electives (excluding courses listed in the department of the student's major, and chemistry, physics, mathematics and statistics) not to exceed a total of four courses or 14 credit hours and limited to two courses in a term (or 1 in a half term).

   b) Additional courses from other groups specially designated in the degree programs under headings such as Related Technical Subjects, Program Subjects, Technical Options or Concentration, or Engineering Electives, when approved by the Program Adviser and together with 2a do not exceed the limits stated in 2a.

The following regulations will apply.

1) The decision to elect a course on pass-fail basis must be made within the first six weeks of the term (or first three weeks of a half-term). The student must make his decision known to the Engineering College Records Office on a form obtained in that office. The student must abide by his decision to take a course for pass-fail once it has been made.

2) The Assistant Dean may approve for a freshman the election of a course offered only on a pass-fail basis.

3) Instructors are not notified of pass-fail elections; they will report grades as usual, A through E. The Records Office will then translate grades as follows:

   a) A grade of C through A in a course elected on a pass-fail basis is considered satisfactory and will be recorded as P (pass-for credit toward the degree and no effect on the grade point average).

   b) A grade lower than C in a course elected on a pass-fail basis is considered unsatisfactory and will be recorded as F (fail-no credit and no effect on grade point average).

4) To be eligible for the Dean's Honor List, a minimum of 12 credit hours (six for a half-term) must be elected for grades; and a minimum of 60 hours of credit must be completed with grades to be eligible for recognition on diploma.
5) If a student has taken a course for pass-fail and subsequently changes his degree program of study such that the course comes into conflict with the stated constraints for pass-fail elections in his new program, the course will be accepted in the new program as follows:
   a) A record of P(pass) is regarded as a satisfactory completion of the program requirement.
   b) A record of F(fail) is regarded as unsatisfactory completion and the course must be repeated for grades.
6) Any request by a student not in accord with the above must be approved by both the Program Adviser and the Assistant Dean.

Course Offered on Pass-Fail Basis. A department or instructor may offer an undergraduate course on the basis that the instructor will report the grade as pass-fail for each student enrolled, and that the grade will be treated on the same basis as when the student chooses to elect a course on pass-fail basis if the following conditions are satisfied:

a) The course is not a required one for any program or department.
b) It is the type of course which might be considered appropriate to a pass-fail grading system. Examples of such courses might be: design; survey-type; individual directed research; laboratory; or undergraduate seminars.
c) It is announced by the Time Schedule and by the instructor at the beginning of the term.

Transferring Out, Withdrawing, 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.

Withdrawing. In order to disenroll after a student has registered (including early registration), he must report to Assistant Dean's Office to complete Withdrawal Notice form. 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.

Disenrollment fees vary from a minimum of $50.00 for first two weeks of a term to full assessed fees for the term after sixth week.

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.

A student who has been absent two terms or more or withdrew for health reasons will be referred to the Health Service for clearance.

Honors

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

Convocations and Awards. Annually, those students who have earned distinguished academic records participate in the University's Honors Convocation. The College and several employers of engineers give special recognition or awards to students with high scholastic achievement, with records of service to the College and its student organizations, or with evidence of extraordinary potential for professional leadership.

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. A student's election to a recognized society will be posted on his academic record.

Recognition on Diploma. A student graduating with at least 60 hours of credit which have been completed with grades 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

Requirements for a Bachelor's Degree

As a basic principle, the quality and level of attainment reached by the student are considered to be of greater significance in determining the requirements and standards for graduation than the completion of a specified number of credit hours.

In order to obtain a bachelor's degree in the College of Engineering, Ann Arbor campus, a student shall meet the following requirements, subject to approval of his program adviser:

1) He must achieve a satisfactory level of attainment in those subjects specified by the program of his choice.
2) He must complete a minimum of 30 credit hours of advanced level College of Engineering courses (300 or higher, as required by his degree program) by enrollment in the College of Engineering, Ann Arbor campus.

3) He may be considered proficient in a designated part of his degree requirement and be allowed recognition of his level of attainment in one or more of the following ways:
   a) By advanced Placement Program examination for college-level work done in high school—see Advanced Placement, under Admission.
   b) By an examination regularly offered by a department of the University—e.g., mathematics and language, or by a recognized testing service.
   c) By transfer of equivalent credit from another recognized college—see Adjustment of Advanced Credit, under Admission with Advanced Standing.
   d) By demonstrating qualification for enrollment in a higher-level course or series—e.g., honors-level, in which case a student may achieve a saving in credit hours.
   e) By demonstrating equivalent and parallel knowledge which enables the student to enroll at an advanced level. In this case, he will not be allowed credit hours on his academic record, but may be excused from enrolling in those courses in which his program adviser judges him proficient. To qualify, the student must petition the program adviser and, as a condition, he may be required to demonstrate his proficiency by an appropriate examination.
4) He must complete at least 30 of his last 36 credit hours of work while enrolled in the College of Engineering, Ann Arbor campus.
5) He must accumulate a final grade-point average of 2.00 or more for all credit hours not taken under the pass-fail option while enrolled in the College of Engineering, Ann Arbor campus (See exception for freshman grade-points).
6) He must file formal application for his diploma—see Diploma and Commencement.

Requirements for Additional Bachelor's Degrees

1) To obtain two bachelor's degrees in the College of Engineering, a student must complete the requirements of both degree programs. In addition, for the second degree, he must complete a minimum of 14 credit hours in pertinent technical subjects over the number required for the first degree. The credit hours used to satisfy each of the two programs must satisfy the cumulative grade-point average requirement of 2.00 or more.
2) To obtain an additional bachelor's degree in the College of Literature, Science, and the Arts, refer to program requirements under Combined Programs with College of Literature Science and the Arts.

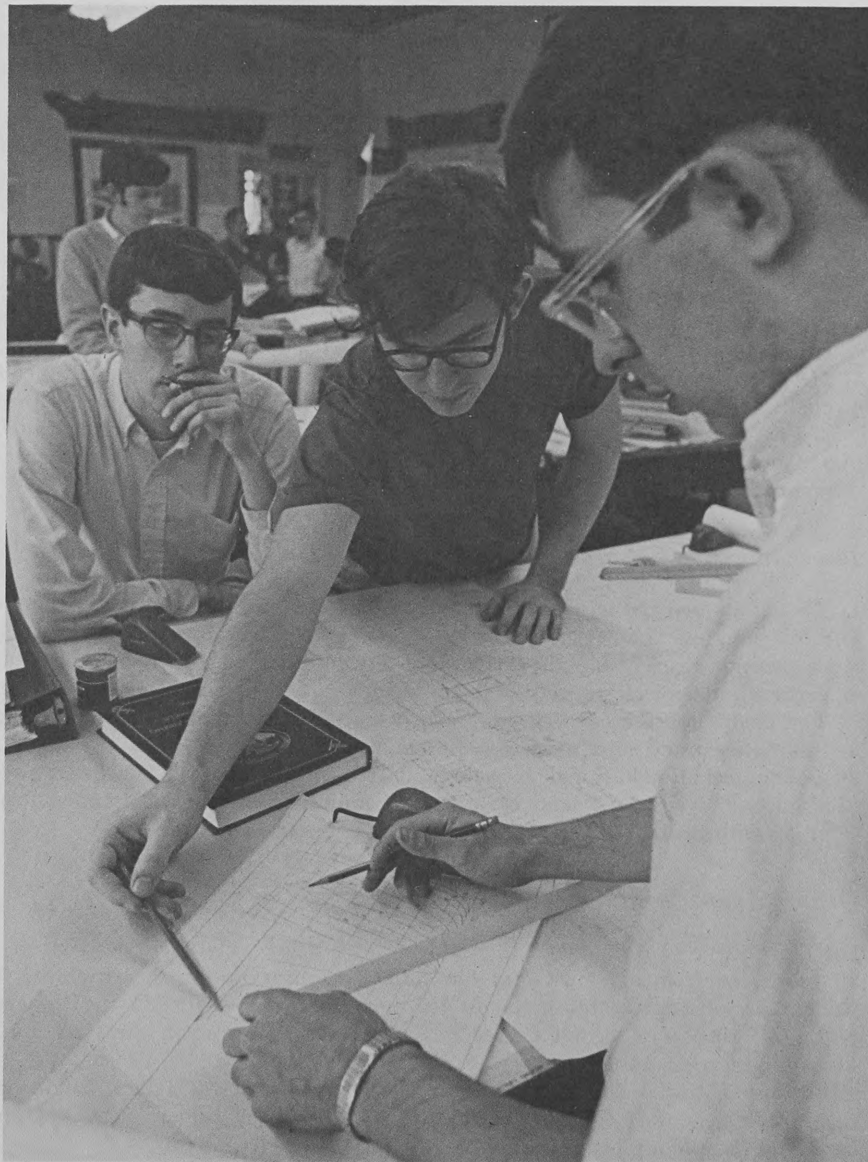
Diploma and Commencement

For the College to recommend the granting of a degree, a student who satisfies all other requirements must also file formal application for the diploma. A student completing the requirements for more than one degree in the College of Engineering or a second degree in Literature, Science, and the Arts must file an application for each.

The application must be submitted to the Records Office, 263 West Engineering Building, at the beginning of the term in which the student is reasonably certain of completing his work for the degree.

When a student does not meet the requirements as planned, or if the degree is not awarded because of indebtedness, he must renew his application at the appropriate time. Degrees are awarded at the end of the fall, winter, and spring-summer terms.

All students who are entitled to receive diplomas are expected to be present at the Commencement exercises appropriate to the date of graduation. Making all arrangements for attending is the student's responsibility.



Undergraduate Degree Programs

Each of the fifteen undergraduate degree programs requires a minimum of 56 credit hours that are common to all programs (see Planning the Student's Program). These are included at the beginning of each of the lists of the programs in the following descriptions.

The remaining 72 hours identify the major or field of specialization in which the student will obtain his bachelor's degree as indicated for each program. In most cases, these may be classified as: Advanced Mathematics and Science; Related Technical Subjects; Program Subjects; and Technical or Free Electives.

Many of the courses required for one program are readily transferred to meet the requirements of another program; this allows a student to change his field of specialization with a minimum of sacrifice, or to work toward satisfying the requirements for two degrees under the requirement of a minimum of 14 extra hours.

Proposed Forthcoming Revisions That Have Been Approved by the Faculty (Subject to Approval by Board of Regents).

1. The name of the program now identified with degree Bachelor of Science in Engineering (Science Engineering) will be changed to Bachelor of Science in Engineering (Engineering Science). The program will continue to provide the elective sequences now available and in addition will include a sequence that would be equivalent to the present Physics program.
2. Physics program to be absorbed into the proposed Bachelor of Science in Engineering (Engineering Science). (See 1)
3. Proposed addition of a new program that will provide freedom for preparation for a terminal bachelor's degree or for a wide variety of post-baccalaureate study opportunities such as business, law, medicine, and teaching.

Students who started either the Science Engineering or Physics program as it appears in this catalog will have the opportunity to complete it.

Elective Studies

Each program provides 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 (minimum 12) concerned with human cultures and relationships—generally identified as humanities and social sciences.

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) elective courses offered by the Department of Humanities, 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 listed under American Culture, Anthropology, Asian Studies, Classical Studies, Economics (except accounting and statistics), Geography (except physical geography), Great Books (not including courses equivalent to Humanities 101 and 102), History, History of Art, Languages and Literature (offerings of all departments), Linguistics (except English as a Foreign Language), Music, Philosophy, Political Science, Psychology, and Sociology.
4) Courses in the College of Engineering that are cross-listed with courses in the College of Literature, Science, and the Arts that satisfy condition (3).
5) A program in American Studies coordinated by Department of Humanities, College of Engineering.

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 military, naval or air science (limited to four hours advanced level for credit).

It is permissible and generally desirable for a student to elect courses in addition to those required for his degree, provided he has a clear understanding with his program adviser. This provides an opportunity to explore areas of cultural and professional interests as well as to enhance the student's 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, dentistry, or education.

Time Requirement for the Bachelor's Degree

The time required to complete a degree program depends on the background, abilities and interests of the individual student. A full-time schedule averaging 16 hours of required subjects will allow a student to complete his degree requirements (128 credit hours) in 8 terms as may be noted from the sample schedules appearing with the several program descriptions. A student who is admitted with advanced preparation, with demonstrated level of attainment, or with ability to achieve at high levels may materially accelerate his progress. A student who elects a Military Officer Education Program or who is partially self-supporting while at the campus may find it desirable to plan a schedule longer than 8 terms.

A student interested in the pursuit of graduate work may, under some conditions receive credit for graduate level work taken in his last term as an undergraduate (refer to the Announcement of the Horace H. Rackham School of Graduate Studies). A course required for bachelor's degree cannot be used for graduate credit also.

Class Standing. The number of credit hours accumulated toward graduation at the close of a given term are used to determine a student's class standing for statistical purposes. Questions concerning class-level designations should be referred to the Assistant Dean's Office.

Underclassmen		*Upperclassmen*	
Class	*Hours*	*Class*	*Hours*
Freshman	0 to 28	Junior	61 to 92
Sophomore	29 to 60	Senior	93 or more

A transfer student is classified in this manner in terms of the tentative adjustment of credit applicable to his elected program; when on a prescribed program he will be a senior when he has 35 hours or less to complete.

Combined Degree Program for Simultaneous Bachelor's Degree from the College of Literature, Science, and the Arts

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

Students enrolled for a bachelors degree in the College of Engineering or the College of Literature, Science, and the Arts may obtain bachelors degrees in both colleges simultaneously by enrolling in the Combined Degree Program which has been established by these two colleges and by fulfilling the requirements as outlined below. This program has been developed to make it convenient for students to obtain a broader education than would normally be possible by enrolling in only one college. It is particularly advantageous for students who wish to develop some depth of understanding in both the technically oriented studies offered in the College of Engineering and the physical, natural, or social sciences and humanities which are available in the College of Literature, Science, and the Arts. Such a combination can provide a truly liberal education in the modern sense, and should be excellent preparation for meeting the problems of modern society which involve to an ever increasing extent both technical and sociological matters.

Program Requirements. Candidates for a Bachelor of Science in Engineering (B.S.E.) combined with a Bachelor of Science (B.S.) or Bachelor of Arts (A.B.) must: (a) satisfy the requirements of one of the degree programs of the College of Engineering; (b) take a minimum of 90 credit hours of work in the College of Literature, Science, and the Arts, satisfy the distribution requirements of that College (except that the usual time limitations for completion of these requirements shall not apply), and fulfill the concentration requirements for one of the Programs of that College; and (c) have a cumulative grade point average of 2.00 or higher.

Candidates for a Bachelor of Science in Engineering (B.S.E.) combined with a Bachelor of General Studies (B.G.S.) must: (a) satisfy the requirements of one of the degree programs in the College of Engineering; (b) take a minimum of 90 credit hours of work in the College of Literature, Science, and the Arts of which 40 credit hours must be for courses numbered 300 or higher that are passed with a grade of C or higher, with no more than 15 of these 40 credit hours to consist of courses in any one department; (c) have a cumulative grade point average of 2.00 or higher.

Because of the great variety of combinations of programs in the two colleges that might be chosen by students under the Combined Degree Program, it is not feasible to list course requirements in detail. Instead, each student should consult the Program Advisers in his field of specialization in each college to develop an optimum set of courses for the particular combination of fields of specialization of interest to him.

In general, counselors working with students in this Combined Degree Program will attempt to minimize the total number of courses required by recommending those which will contribute toward fulfilling requirements in both colleges whenever possible. Thus, many of the courses needed to fulfill the 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, and many engineering science courses may be used to fulfill concentration cognates. Likewise, requirements in literature, humanities, and social sciences for the College of Engineering can be selected from courses taken to fulfill distribution requirements in the College of Literature, Science and the Arts. In this way it is usually possible for students carrying average loads of 16 credit hours per term to complete the requirements of this Combined Degree Program in 10 or 11 terms.

In order to insure that the courses selected apply effectively and efficiently to both degrees, the student must assume responsibility for maintaining liaison between his two advisers. He should become throroughly familiar with the general regulations and procedures of both colleges and with the academic requirements and course offerings in both fields of specialization, as set forth in the Announcements of the two colleges. In case unusual difficulties or special problems arise the student should consult the advisers listed above for this Combined Degree Program, who will work with him and his advisers in attempting to find a solution.

Regulations. The following regulations for administering enrollment will apply:

1) Students initially enrolled in either the College of Engineering or the College of Literature, Science, and the Arts may enter this Combined Degree Program.
2) To be qualified for admission a student should normally have completed thirty credit hours of course work with a 2.40 cumulative grade point average.
3) A student considering this program should consult one of the advisers listed above, to apply for admission and to establish counseling procedures as soon as his interest is firmly established, preferably by the end of his first year.
4) Upon applying for admission, a student must indicate his field of specialization in each college. His application for admission must then be approved by the academic adviser in each of these fields of specialization and by the assistant dean of each college.
5) After being admitted to this program, a student will continue to register in the college in which he first enrolled, and that college will be responsible for maintenance of his primary academic record and for transmitting to the other college at the end of each term the number of copies of his transcript needed for counseling and other official purposes in that college.
6) A student participating in this program should consult with the program

adviser for his field of specialization in each college prior to classification each term to obtain approval of his course elections.

7) To be permitted to continue in this Combined Degree Program, a student must satisfy the requirements of both colleges with regard to good scholastic standing.
8) If a student in good scholastic standing wishes to withdraw from this Combined Degree Program, he may continue to enroll for a single degree in his original College. If he wishes to transfer, he may do so provided his record is acceptable to the other college. He should consult the Assistant Dean of the College in which he is registered for instructions. A student not in good scholastic standing will normally remain in the college in which he initially enrolled and be subject to the rules of that college.
9) Upon satisfying the program requirements of both colleges, the student will receive both degrees on the same date. At the beginning of the term in which he expects to graduate, he must file a diploma application in each college and must request his program adviser in each college to submit an appropriate notification of his eligibility for graduation to the Records Office of that college.

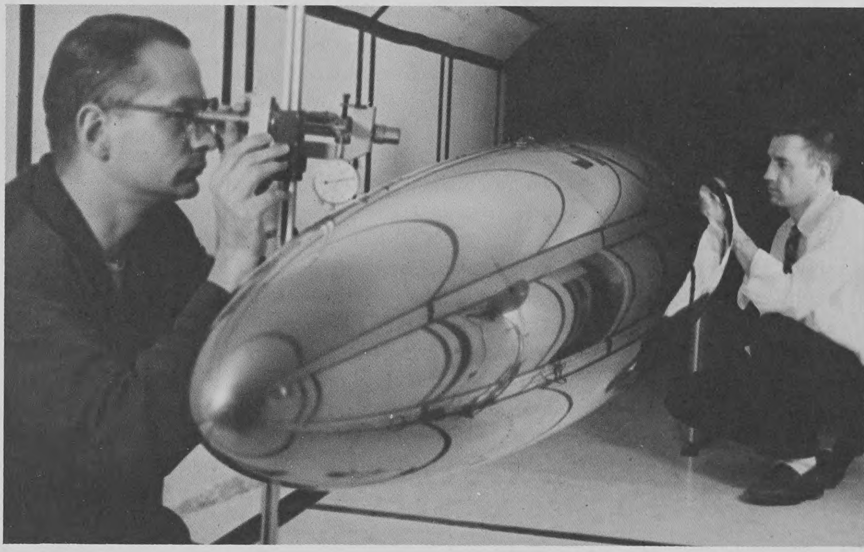
Representative Possible Schedule

In an effort to provide the interested student, both freshman and transfer, with a sample schedule, the information for a number of the 15 degree programs includes a schedule that is an example of one leading to graduation in 8 terms; this is for informational purposes only and should not be construed to mean that students are required to follow the schedule exactly. Generally, it will be modified for a student electing Military Officer Education Program, or a freshman admitted with advanced placement.

A transfer student attending a community or liberal arts college and pursuing a pre-engineering degree program, may not be able to follow a similar schedule because of a lack of certain offerings in his college. If this is the case, he should elect humanities and social sciences subjects in place of the professional courses listed in the schedule during terms 3 and 4.

Even though a student is unable to maintain the pace of the schedule printed, he will find it desirable to follow the order in which the courses are scheduled to satisfy prerequisites.

Military Officer Education Program courses are not included in the sample schedules; a student who elects and completes the advanced program for his commission should consult his program adviser on the use of a maximum of four credit hours in an appropriate elective category.



Aerospace Engineering

Program Adviser: Professor H. 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.

Students may earn an additional B.S.E. Degree in another program such as Naval Architecture and Marine Engineering, often requiring only one extra term to complete. For details on requirements for additional Bachelor's degrees see page 43.

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 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 Bachelor of Science in Engineering (Aerospace Engineering—B.S.E. (Aerospace E.)—must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms.

Courses		*Term*	*Enrolled*						
	Hrs.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Subjects required by all programs (58 hrs.)									
See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102—Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101—Graphics, and 102—Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	–	3	3
Humanities and Social Sciences	14	–	4	3	3	–	–	–	4
Advanced Mathematics (4 hrs.)									
Math. 450, Adv. Math. for Engineers I	4	–	–	–	–	4	–	–	–
(Note requirement below under Technical or Free Electives)									
Related Technical Subjects (18 hrs.)									
Eng. Mech. 211, Intro. to Solid Mechanics	4	–	–	4	–	–	–	–	–
Eng. Mech. 340, Intro. to Dynamics	4	–	–	–	4	–	–	–	–
Mat.-Met. Eng. 250, Prin. of Eng. Materials	3	–	–	–	3	–	–	–	–
Mech. Eng. 335, Thermodynamics I	3	–	–	–	3	–	–	–	–
Elec. Eng. 314, Cct. Anal. and Electronics	3	–	–	–	–	3	–	–	–
Elec. Eng. 315, Cct. Anal. and Electronics Lab.	1	–	–	–	–	1	–	–	–
Program Subjects (37 hrs.)									
Aero. Eng. 200, Gen. Aeron. and Astronautics	2	–	–	2	–	–	–	–	–
Aero. Eng. 314, Structural Mechanics I	4	–	–	–	–	4	–	–	–
Aero. Eng. 320, Aerodynamics I	4	–	–	–	–	4	–	–	–
Aero. Eng. 330, Propulsion I	3	–	–	–	–	–	3	–	–
Aero. Eng. 414, Structural Mechanics II	4	–	–	–	–	–	4	–	–
Aero. Eng. 420, Aerodynamics II	4	–	–	–	–	–	4	–	–
Aero. Eng. 430, Propulsion II	4	–	–	–	–	–	–	4	–
Aero. Eng. 441, Mechanics of Flight	4	–	–	–	–	–	4	–	–
Aero. Eng. 471, Automatic Control Systems	4	–	–	–	–	–	–	4	–
Aero. Eng. 481, Airplane Design, or	4	–	–	–	–	–	–	–	4
Aero. Eng. 482, Sounding Rocket and Payload Design, or									
Aero. Eng. 483, Aerospace System Design									
Technical or Free Electives (11 hrs.)									
Including 2 upper level courses in mathematics, physics, or engineering	11	–	–	–	–	–	–	6	5
Total	128	15	16	17	16	16	15	17	16

Chemical Engineering

Program Adviser: Professor R. H. Kadlec, 3036 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, process design, 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, chemical, and engineering disciplines to produce antibiotics, frozen foods, fermented products, vaccines, and life support systems in medical therapy. Chem. Eng. 417, 434, 516; Biochem. 415, Zool. 101.

Chemical Reaction Engineering. A study in depth of the engineering variables of chemical reactions, which constitute the basic ingredient of all chemical processes. Chem. Eng. 528, 625, 628, 648; Math. 404.

Electrochemical and Corrosion. The study of electrochemical processes as they relate to energy conversion (batteries and fuel cells), electro-synthesis, electroplating, and corrosion. Corrosion and corrosion control are viewed in terms of materials selection and environmental effects. Chem. Eng. 573, 648; Chem. 481 and 482.

Environmental Engineering. The application of chemical engineering operations and technology to the prevention, control and abatement of pollution in the air, water and process wastes. Chem. Eng. 417, 434, 516, 546, 549.

Graduate Studies. Preparation for a more intensive and penetrating study of the field of chemical engineering and of frontier problems of research. Chem. Eng. 407, 537, 547; Math. 450.

Information and Control. The measurement and control of variables in physical and chemical processes encountered in industry or space-age research. Chem. Eng. 566; Math. 404, 448; C.I.C.E. 450, 451, 482.

Machine Computation. The application of electronic computers to the solution of engineering problems. Chem. Eng. 508; Math. 404, 473, 474; C.I.C.E. 482.

Materials. A knowledge of the preparation, structure, and behavior of materials that are used in production or pilot plant work. Mat.-Met. Eng. 351, 371, 450, 451, 455, 472, 475, 486, 512, 550, 552; Eng. Mech. 416.

Medical. Chemical Engineering students can satisfy the course entrance requirements to the University of Michigan Medical School by completing one year of foreign language (humanities elective) and eight hours of biology (elective) within the chemical engineering program.

Molecular. Concentration on the properties of molecules as they determine the macroscopic behavior of liquid or solid matter such as plastics or transistors. Mat.-Met. Eng. 451, 512; 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. 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. Mat.-Met. Eng. 451, 511, 512; Chem. 538; Physics 418.

Petroleum. The production, transportation, refining and chemical processing of oil and natural gas from the ground. Chem. Eng. 585, 587; Geol. 218.

Systems. The methods of combining individual operations into a working whole with a maximum of efficiency and optimization. Chem. Eng. 566, 588; C.I.C.E. 450; Math. 448; Ind. Eng. 472.

Facilities

The facilities located in the East Engineering Building include 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, liquid metal, ultrasonics, electrochemistry, corrosion, and thermodynamics laboratories; and in George Granger Brown Laboratory, large and pilot scale heat transfer, mass transfer, kinetics, and separations processes equipment, process control and data acquisition digital computer system, analog computation, process simulation, particle and aerosol dynamics, rheology and biochemical engineering research.

Requirements

Candidates for the degree Bachelor of Science in Engineering (Chemical Engineering)—B.S.E. (Ch.E.)—must complete the following program.

Schedule below is an example of one leading to graduation in 8 terms.

Courses	*Hrs.*	*Term Enrolled* 1	2	3	4	5	6	7	8
Subjects required by all programs (56 hrs.) See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102—Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101—Graphics, and 102—Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	–	3	3
Humanities and Social Sciences (to include a course in economics)	12	–	–	–	4	4	4	–	–
Advanced Science (18 hrs.)									
Chem. 106, General and Inorganic Chemistry	4	–	4	–	–	–	–	–	–
Chem. 225, Organic Chemistry	3	–	–	3	–	–	–	–	–
Chem. 226 and 227, Organic Chem. and Lab.	5	–	–	–	5	–	–	–	–
Chem. 468, Physical Chemistry	3	–	–	–	–	3	–	–	–
Chem. 469, Physical Chemistry	3	–	–	–	–	–	3	–	–
Related Technical Subjects (8 hrs.)									
Eng. Mech. 211, Intro. to Solid Mechanics	4	–	–	–	–	4	–	–	–
Elec. Eng. 314, Cct. Anal. and Electronics	3	–	–	–	–	–	3	–	–
Elec. Eng. 315, Cct. Anal. and Electronics Lab.	1	–	–	–	–	–	1	–	–
Program Subjects (32 hrs.)									
Chem. Eng. 230, Thermo. I and 231, Lab.	4	–	–	4	–	–	–	–	–
Chem. Eng. 330, Thermo. II	3	–	–	–	–	–	3	–	–
Chem. Eng. 341, Rate Proc. I	3	–	–	–	3	–	–	–	–
Chem. Eng. 342, Rate Proc. II; 344, Lab.	4	–	–	–	–	4	–	–	–
Chem. Eng. 343, Separation Processes	3	–	–	–	–	–	3	–	–
Chem. Eng. 444, Gases, Liquids, Solids and Surfaces	3	–	–	–	–	–	–	3	–
Chem. Eng. 460, Eng. Operations Lab.	3	–	–	–	–	–	–	3	–
Chem. Eng. 486, Eng. Materials in Design	3	–	–	–	–	–	–	–	3
Chem. Eng. 487, Prin. of Chem. Eng. Des.	3	–	–	–	–	–	–	3	–
Chem. Eng. 488, Practice of Chem. Eng. Des.	3	–	–	–	–	–	–	–	3
Electives (14 hrs. including 4 hrs. free electives).	14	–	–	–	–	2	–	5	7
Total	128	15	16	15	15	17	17	17	16

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, synthetic foods, biomedical devices and artificial organs.

Electives adapted for the program in biochemical engineering are: Chem. 228; Zool. 100; Chem. Eng. 417, 434, 516, 546; Biol. Chem. 415, 416.

Combined Programs

Chemical, Materials, and Metallurgical Engineering

Combined degrees may be obtained in chemical engineering and materals engineering, or chemical engineering and metallurgical engineering.

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.

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.

Environmental, Sanitary, and Water Resources Engineering. Specialization in this field may be in one or more of three areas: 1) municipal and industrial water and wastewater treatment, water distribution and waste collection, water quality and water pollution control, the improvement and regulation of natural waters for municipal, industrial, and recreational use; 2) water resources development and management, the analysis and design of water resource systems; 3) environmental design for control of solid wastes and air and water pollution, management of engineering problems in the urban environment.

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 and Hydrological 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.

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.

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 George Granger Brown Laboratory on the North Campus houses the concrete research laboratory, 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.

Requirements

Candidates for the degree Bachelor of Science in Engineering (Civil Engineering)-B.S.E. (C.E.)-must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms.

Courses	*Hrs.*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
		Term Enrolled							
Subjects required by all programs (56 hrs.) See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102—Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101—Graphics, and 102—Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	–	3	3
Humanities and Social Sciences (Note A)	12	–	4	2	–	3	–	3	–
Advanced Mathematics (3 hrs.)									
Elective	3	–	–	–	–	3	–	–	–
Related Technical Subjects (20 hrs.)									
Eng. Mech. 211, Intro. to Solid Mechanics	4	–	–	4	–	–	–	–	–
Eng. Mech. 340, Introduction to Dynamics	4	–	–	–	4	–	–	–	–
Elec. Eng. 314, Cct. Anal. and Electronics	3	–	–	–	–	–	–	3	–
Mech. Eng. 335, Thermodynamics I	3	–	–	–	3	–	–	–	–
Mat.-Met. Eng. 250, Prin. of Eng. Materials	3	–	–	3	–	–	–	–	–
Civ. Eng. 324(Eng. Mech. 324), Fluid Mech.	3	–	–	–	–	3	–	–	–
Program Subjects (41 hrs.)									
Civ. Eng. 262, Geodetic Engineering I	4	–	–	–	–	4	–	–	–
Civ. Eng. 312, Theory of Structures	3	–	–	–	3	–	–	–	–
Civ. Eng. 313, Elementary Des. of Structures	3	–	–	–	–	3	–	–	–
Civ. Eng. 351, Anal. of Civil Eng. Materials	2	–	–	–	2	–	–	–	–
Civ. Eng. 400, Contracts and Specifications	2	–	–	–	–	–	–	2	–
Civ. Eng. 415, Reinforced Concrete	3	–	–	–	–	–	3	–	–
Civ. Eng. 420, Hydrology I	2	–	–	–	–	–	2	–	–
Civ. Eng. 421, Hydraulics	2	–	–	–	–	–	2	–	–
Civ. Eng. 445, Eng. Properties of Soil	3	–	–	–	–	–	3	–	–
Civ. Eng. 470, Transportation Engineering	3	–	–	–	–	–	3	–	–
Civ. Eng. 480, Water Supply and Treatment	3	–	–	–	–	–	–	3	–
Civ. Eng. 481, Sewerage and Sewage Treatment	2	–	–	–	–	–	–	–	2
Technical Concentration (Note B)	9	–	–	–	–	–	–	3	6
Technical Electives (8 hrs.) (Note C)	8	–	–	–	–	–	3	–	5
Total	128	15	16	17	15	16	16	17	16

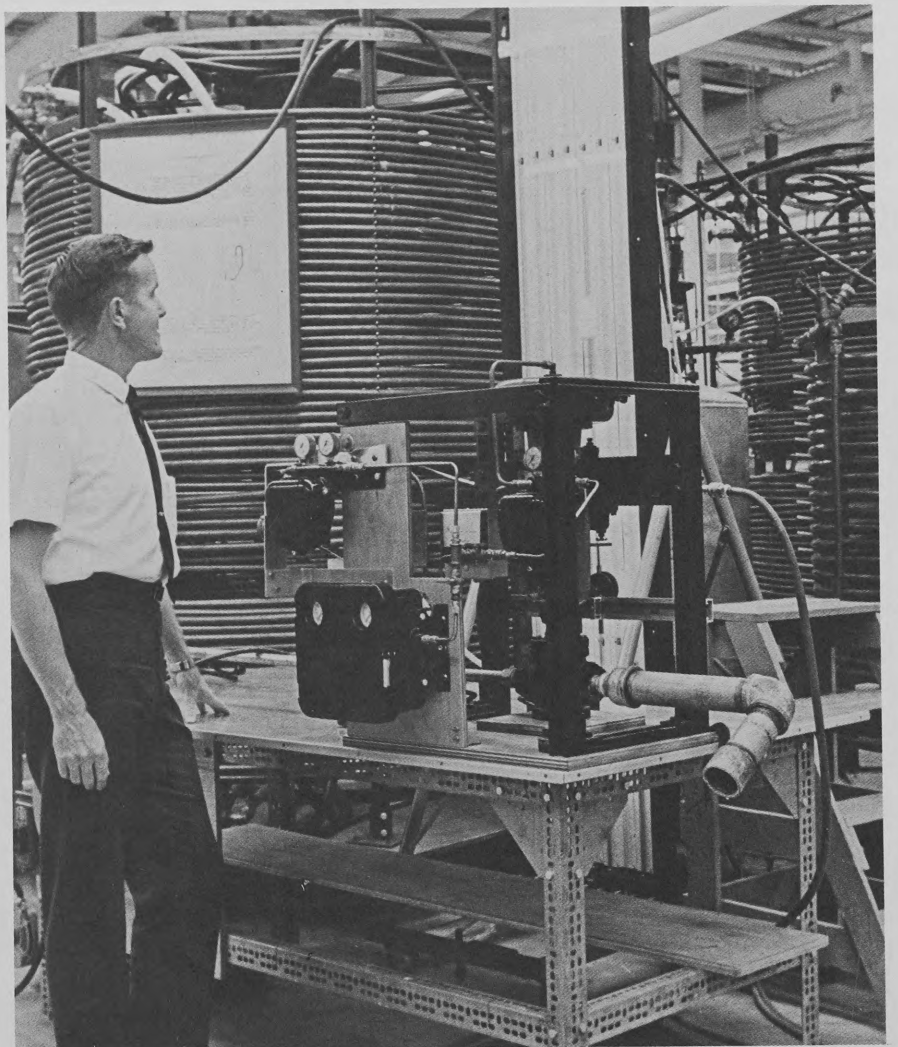
Note A. At least 3 hours must be economics and 3 hours must be in humanities.

Note B. The technical concentration 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 concentration requirements are available in the following areas:

1) Construction Engineering—Adviser: Professor Harris
2) Environmental and Water Resources Engineering—Adviser: Professor Weber
3) Geodetic Engineering—Adviser: Professor Berry

4) Highway Engineering—Adviser: Associate Professor Cortright
5) Hydraulic and Hydrological Engineering—Adviser: Professor Brater
6) Municipal Engineering—Adviser: Associate Professor Glysson
7) Sanitary Engineering—Adviser: Professor Borchardt
8) Soils Engineering—Adviser: Professor Richart
9) Structural Engineering—Adviser: Associate Professor Rumman
10) Transportation and Traffic Engineering—Adviser: Professor Cleveland

Note C. 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 courses in one of the branches of engineering, in mathematics, or in one of the natural sciences. A maximum of 4 credit hours of advanced Military Officer Education Program course work may be considered as Technical Electives.



Electrical Engineering

Program Advisers: Option 1: Professor R. E. Hiatt; Option 2: Associate Professor T. J. Nelson; Option 3: Associate Professor R. A. Volz, Chief Adviser, Student Counselling Office, 4084 East Engineering

Modern electrical engineering is a broad and diverse field. The expanding role of the electrical engineer in today's society reflects the variety and scope of this exciting profession. The curriculum offered by the Electrical Engineering Department is designed to provide the student with a fundamental background in the basic theoretical concepts and technological principles which constitute the foundations of modern electrical engineering and, at the same time, the opportunity to emphasize subject areas in which he has a particular interest. The curriculum requirements are flexible enough so that the student, with the assistance and approval of a program adviser, may design his program to achieve a variety of objectives. For example, the student may emphasize the applied and experimental aspects of electrical engineering or he may concentrate on subjects requiring an analytical or theoretical treatment. By selecting one of the three options, (1) Electronics and Design, (2) Electrical Science, or (3) Computer, Information and Control Engineering, and by taking appropriate elective courses, the student may obtain either a broad exposure to the important fields of modern electrical engineering or he may specialize to a limited extent in one or more areas of concentration. These areas are grouped according to options as follows: (1) Electronics and Design: Industrial and Medical Electronics, Measurements and Instrumentation, Systems Engineering, Modeling and Simulation, Project Design and Engineering Practice, and Energy Conversion; (2) Electrical Science: Radiation and Propagation, Electro-Optics, Quantum Electronics, Integrated Electronics, Materials, Solid State Devices, Microwaves, and Bio-electrical Science; (3) Computer, Information and Control Engineering: Computers, Communications, Information Systems, and Control Systems.

Throughout his studies the student works with modern laboratory equipment and is exposed to the most recent analytical techniques and technological developments in the field. Association with an outstanding faculty, most of whom are actively engaged in engineering research or professional consulting, serves to acquaint the student with the opportunities and rewards available to the practicing electrical engineer. If further specialization and a high degree of competence in a particular area is desired, the student may be encouraged to seek an advanced degree. The advanced degrees available at the master's level and the requirements for these degrees are described under Graduate Studies.

Facilities

The facilities of the Electrical Engineering Department include instructional laboratories in the East Engineering Building and the following laboratories devoted primarily to research: Cooley electronics, radiation, electron physics, space physics, systems engineering, bio-electrical science, plasma, and power-systems. Electrical engineering students also participate in research programs conducted in various laboratories of the Institute of Science and Technology, notably the radar and optics and the infrared laboratories. The laboratory facilities available to the student include instructional digital and analogue computers and logic design modules. In addition, teletype and graphical display terminals connected on-line with the Computing Center are available for student use in a number of electrical engineering courses. A recently developed integrated circuits laboratory and a solid state devices laboratory provide instruction in the physical processes and techniques employed in these rapidly growing fields.

Requirements

Candidates for the degree Bachelor of Science in Engineering (Electrical Engineering)-B.S.E. (E.E.)-must complete the following program.

Schedule below is an example of one leading to graduation in 8 terms.

Courses		*Term*	*Enrolled*						
	Hrs.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Subjects required by all programs (56 hrs.)									
See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102—Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101—Graphics, and 102—Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	3	–	3	–
Humanities and Social Sciences	12	–	4	4	–	–	–	–	4
Related Technical Subjects required by each option (10 hrs.)									
Mat.-Met. Eng. 250, Prin. of Eng. Materials	3	–	–	3	–	–	–	–	–
Physics 242, General Physics III	3	–	–	–	3	–	–	–	–
Mech. Eng. 331, Classical & Statistical Thermodyn.	4	–	–	–	4	–	–	–	–
Option Subjects (62 hrs.)—See schedule below.									
Option 1, Electronics and Design									
*Elec. Eng. 211, Resistive Network Anal.	3	–	–	–	3	–	–	–	–
*Elec. Eng. 300, Math. Methods in Sys. Anal.	3	–	–	–	–	3	–	–	–
*Elec. Eng. 305, Math. Methods of Field Anal.	3	–	–	–	–	3	–	–	–
*Elec. Eng. 311, Dynamic Network Analysis	2	–	–	–	–	2	–	–	–
*Elec. Eng. 312, Electronic Circuits I	3	–	–	–	–	–	3	–	–
*Elec. Eng. 325, Electromagnetic Field Theory I	4	–	–	–	–	4	–	–	–
*Elec. Eng. 331, Electrical Circuits Lab.	2	–	–	–	–	–	2	–	–
Elec. Eng. 343, Energy Conversion	3	–	–	–	–	–	3	–	–
Elec. Eng. 363, Measurements and Instrument.	3	–	–	–	–	–	–	3	–
Elec. Eng. 380, Prin. of Physical Electronics	3	–	–	–	–	–	3	–	–
Elec. Eng. 381, Physical Electronics Lab.	2	–	–	–	–	–	–	2	–
Elec. Eng. 472, Prin. of Electrical Design	3	–	–	–	–	–	–	–	3
Electives	28	–	–	2	3	–	6	8	9
Elec. Eng. 350(3), 365(4), or 432(3) — 3 or 4 hrs.									
Technical Electives — 17 hrs.									
To include 12 hrs. at 300 level or higher and at least 6 hrs. of non-Elec. Eng. courses such as Eng. Mech. 340(4), 218(3), 345(3), Ind. Eng. 310(3), Physics 401(3), 402(3), Chem. 265(4), Math. (Com. Sci.) 473(3), Stat. 310.									
Free Electives — 7 to 8 hrs.									
Total	128	15	16	17	16	15	17	16	16

*Common to each option program

Option 2. Electrical Science

*Elec. Eng. 211, Resistive Network Anal.	3	–	–	–	3	–	–	–	–
*Elec. Eng. 300, Math. Methods in Sys. Anal.	3	–	–	–	–	3	–	–	–
*Elec. Eng. 305, Math. Methods of Field Anal.	3	–	–	–	–	3	–	–	–
*Elec. Eng. 311, Dynamic Network Analysis	2	–	–	–	–	2	–	–	–
*Elec. Eng. 312, Electronic Circuits I	3	–	–	–	–	–	3	–	–
*Elec. Eng. 325, Electromagnetic Field Theory I	4	–	–	–	–	4	–	–	–
*Elec. Eng. 331, Electrical Circuits Lab.	2	–	–	–	–	–	2	–	–
Elec. Eng. 326, Electromag. Field Theory II	3	–	–	–	–	–	3	–	–
Elec. Eng. 380, Physical Electronics	3	–	–	–	–	–	3	–	–
Elec. Eng. 381, Physical Electronics Lab.	2	–	–	–	–	–	–	2	–
Elec. Eng. 425, Electrodynamics	3	–	–	–	–	–	–	3	–
Elec. Eng. 483, Physical Electronics II	3	–	–	–	–	–	–	3	–
Elec. Eng. 421, or Elec. Eng. 484	2	–	–	–	–	–	–	–	2
Electives	26	–	–	2	3	–	6	5	10
Elec. Eng. 350(3), 365(4), 430(3), or 432(3) — 3 4 hrs.									
Technical Electives — 17 hrs. To include 12 hrs. at 300 level or higher and at least 6 hrs. of non-Elec. Eng. courses such as Eng. Mech. 340(4), 218(3), 345(3), Ind. Eng. 310(3), Physics 401(3), 402(3), Chem. 265(4), Math. (Com. Sci.) 473(3), Stat. 310.									
Free Electives — 5-6 hrs.									
Total	128	15	16	17	16	15	17	16	16

Option 3, Computer, Information and Control Engineering

*Elec. Eng. 211, Resistive Network Anal.	3	–	–	–	3	–	–	–	–
*Elec. Eng. 300, Math. Methods in Sys. Anal.	3	–	–	–	–	3	–	–	–
*Elec. Eng. 305, Math. Methods of Field Anal.	3	–	–	–	–	3	–	–	–
*Elec. Eng. 311, Dynamic Network Analysis	2	–	–	–	–	2	–	–	–
*Elec. Eng. 312, Electronic Circuits I	3	–	–	–	–	–	3	–	–
*Elec. Eng. 325, Electromag. Field Theory I	4	–	–	–	–	4	–	–	–
*Elec. Eng. 331, Electrical Circuits Lab.	2	–	–	–	–	–	2	–	–
Elec. Eng. 350, Intro. to Linear Sys. and Control	3	–	–	–	–	–	3	–	–
Elec. Eng. 351, Control Systems Laboratory	2	–	–	–	–	–	–	2	–
Elec. Eng. 365, Digital Computer Engineering	4	–	–	–	–	–	4	–	–
Elec. Eng. 366, Digital Computer Eng. Lab.	2	–	–	–	–	–	–	–	2
Elec. Eng. 432, Communication Signals and Cct.	3	–	–	–	–	–	–	3	–
Electives	28	–	–	2	3	–	4	9	10
Math. 417(3), 412(3), or 571(3), or C.I.C.E 412(3) — 3 hrs.									
Technical Electives — 17 hrs. To include 12 hrs. at 300 level or higher and at least 6 hrs. of non-Elec. Eng. courses such as Eng. Mech. 340(4), 218(3), 345(3), Ind. Eng. 310(3), Physics 401(3), 402(3), Chem. 265(4), Math. (Com. Sci.) 473(3), Stat. 310.									
Free Electives — 8 hrs.									
Total	128	15	16	17	16	15	16	17	16

* Common to each option program.

Engineering Mechanics

Program Co-advisers: Assistant Professor R. A. Scott, 201 West Engineering; Professor Hadley J. 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 and women with training in the field of engineering mechanics are sought by organizations of all kinds, particularly by those working on modern developments. Most persons in the field are engaged in highly technical work, but many, like other engineers, enter supervision and management.

A student majoring in engineering mechanics takes 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 Bachelor of Science in Engineering (Engineering Mechanics)-B.S.E. (E.M.)—must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms.

Courses	*Hrs.*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
		Term Enrolled							
Subjects required by all programs (58 hrs.)									
See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102—Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101—Graphics, and 102—Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	–	3	3
Humanities and Social Sciences	14	–	4	3	3	–	–	–	4
Advanced Mathematics (10 hrs.)									
Math. 404, Differential Equations	3	–	–	–	–	3	–	–	–
Math. 450, Adv. Math. for Eng. I	4	–	–	–	–	–	4	–	–
Math. 552, Fourier Series and Applications	3	–	–	–	–	–	–	3	–
Related Technical Subjects (18-21 hrs.)									
Eng. Materials—e.g., Mat.-Met. Eng. 250	3	–	–	3	–	–	–	–	–
Elec. Eng.—e.g., Elec. Eng. 314, 315, and 442, or 215 and 337	8	–	–	–	–	4	4	–	–
Mod. Phys.—e.g., Phys. 307 or Nuc. Eng. 411	3	–	–	–	–	3	–	–	–
Thermodynamics—e.g., Mech. Eng. 331 or 335, or Chem. 265, or Physics 406	3	–	–	–	3	–	–	–	–
Eng. Des.—e.g., Civ. Eng. 313 or Mech. Eng. 343	3	–	–	–	–	3	–	–	–
Program Subjects (28 hrs.)									
Basic Eng. Mech.—typical courses:									
Eng. Mech. 218, Statics	3	–	–	3	–	–	–	–	–
Eng. Mech. 345, Dynamics	3	–	–	–	3	–	–	–	–
Eng. Mech. 211 or 319, Mech. of Solids	4	–	–	–	4	–	–	–	–
Eng. Mech. 324, Fluid Mechanics	3	–	–	–	–	3	–	–	–
Eng. Mech. 442, Intermediate Dynamics	3	–	–	–	–	–	–	3	–
Eng. Mech. 422, Intermediate Mech. of Fluids	3	–	–	–	–	–	–	–	3
Eng. Mech. 412, Intermediate Mech. of Material	3	–	–	–	–	–	–	–	3
Eng. Mech. 328, Fluid Mech. Lab.	1	–	–	–	–	–	–	–	1
Eng. Mech. 402, Experimental Stress Anal.	3	–	–	–	–	–	–	3	–
Eng. Mech. 403, Experimental Mech.	2	–	–	–	–	–	2	–	–
Technical Electives (11 to 14 hrs.)									
Engineering, science, and mathematics	11-14	–	–	–	–	–	6	4	2
Total	128	15	16	17	16	16	16	16	16

It is required that the technical electives in engineering, science and mathematics include at least one sequence which consists of at least three courses or two courses beyond a required course. It is recommended that other electives be ones which broaden or extend the students' knowledge of mechanics. Examples are Eng. Mech. 525 and 527 and courses from sequences other than that chosen, such as Eng. Mech. 411, 541, 507, and 523. 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 must 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, and 442 are as follows:

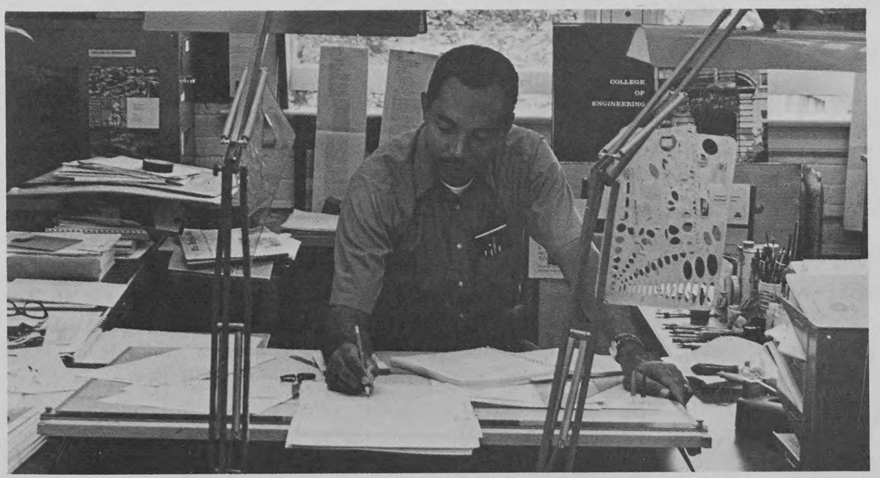
Dynamics
Aero. Eng. 441, Mechanics of Flight and
C.I.C.E. 482, Applications of the Analog Computer
or
C.I.C.E. 450, Feedback Control I

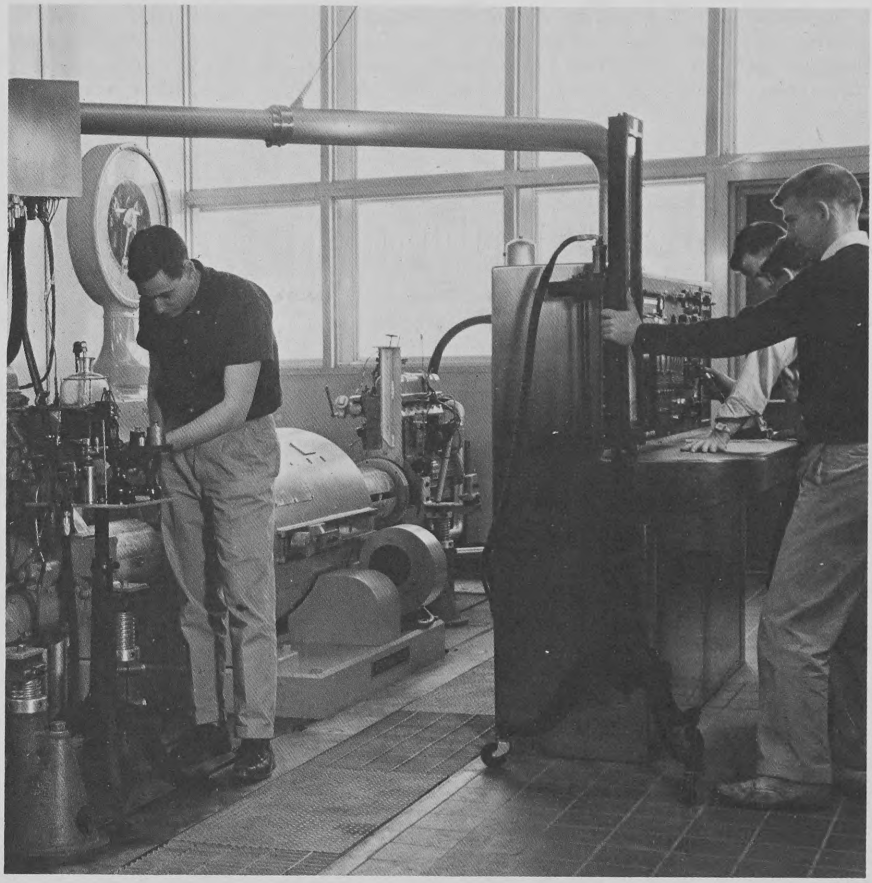
Mechanics of Vibrations
Eng Mech. 541, Intermediate Vibration Theory and
Eng. Mech. 545, Vibrations of Continuous Media
or
Eng. Mech. 548, Lattice Dynamics

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

Mechanics of Fluids and Hydraulics
Eng. Mech. 523, Mechanics of Viscous Fluids I and
Eng. Mech. 527, Thermodynamics and
Eng. Mech. 529, Advanced Laboratory in Mechanics of Fluids
or
Mech. Eng. 421, Dynamics and Thermodynamics of Compressible Flow
or
Civ. Eng. 421, Hydraulics
or
Aero. Eng. 520, Gasdynamics I

Foundations of Continuum Mechanics
Eng. Mech. 527, Thermodynamics and
Eng. Mech. 507, Theory of a Continuous Medium I and
Eng. Mech. 555, Statistical Foundations of Mechanics or
Eng. Mech. 548, Lattice Dynamics





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 engineeering 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.

Students may earn an additional B.S.E. degree in naval architecture and marine engineering under a combined program which allows for substantial substitution of courses in one curriculum for those required in the other.

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.

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 Bachelor of Science in Engineering (Industrial Engineering)-B.S.E. (Ind. E.)-must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms.

Courses		*Term*	*Enrolled*						
	Hrs.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Subjects required by all programs (56 hrs.)									
See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102—Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101—Graphics, and 102—Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	–	3	3
Humanities and Social Sciences	12	–	4	4	–	–	–	–	4
Statistics (6 hrs.)									
Stat. 310, Elem. of Prob. & Math. Stat. I.	3	–	–	–	–	3	–	–	–
Stat. 311, Elem. of Prob. & Math. Stat. II	3	–	–	–	–	–	3	–	–
Related Technical Subjects (15 hrs.)									
Eng. Mech. 211, Intro. to Solid Mech.	4	–	–	4	–	–	–	–	–
Mat.-Met. Eng. 250, Prin. of Eng. Materials	3	–	–	–	3	–	–	–	–
Mech. Eng. 335, Thermodynamics I	3	–	–	–	–	3	–	–	–
Mech. Eng. 252, Eng. Mat. and Mfg. Proc.	2	–	–	–	–	–	2	–	–
Elec. Eng. 215, Network Analysis	3	–	–	–	–	3	–	–	–
or									
Elec. Eng. 314, Circuit Analysis and Electronics									
Program Subjects (30 hrs.)									
Ind. Eng. 300, Intro. to Operating Systems	3	–	–	–	3	–	–	–	–
Ind. Eng. 310, Operations Res.	3	–	–	–	3	–	–	–	–
Ind. Eng. 315, Stochastic Industrial Proc.	3	–	–	–	–	–	3	–	–
Ind. Eng. 333, Human Performance	3	–	–	–	–	3	–	–	–
Ind. Eng. 373, Data Processing	3	–	–	–	3	–	–	–	–
Ind. Eng. Electives (15 hrs)	15	–	–	–	–	3	3	6	3
Technical Electives (15 hrs.)									
(At least 9 hrs. must be non-Ind. Eng.)	15	–	–	–	–	–	6	5	4
Free Electives (6 hrs.)	6	–	–	–	–	–	–	3	3
Total	128	15	16	16	15	15	17	17	17

Materials and Metallurgical Engineering

Program Adviser: Professor W. C. Bigelow, 4213 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 importance 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, polymers 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 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 provides 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.

Combined Programs

Chemical, Materials, and Metallurgical Engineering

Combined degrees in chemical engineering and materials engineering, or chemical engineering and metallurgical engineering provide many advantages. Students in metallurgical or materials engineering who wish a second degree in chemical engineering should consult the two program advisers to work out appropriate course elections. A combined program in materials and metallurgical engineering is not recommended because of the basic similarities of these programs.

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 Bachelor of Science in Engineering (Materials Engineering)-B.S.E. (Mat. E.)-must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms.

Courses	*Hrs.*	*Term Enrolled* 1	2	3	4	5	6	7	8
Subjects required by all programs (58 hrs.)									
See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102–Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101–Graphics, and 102–Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	–	3	3
Humanities (0-6), Social Sciences (6-12) including Economics, and Related Subjects (0-6)	14	–	–	4	3	3	4	–	–
Advanced Mathematics (3 hrs.)									
Mathematics Elective	3	–	–	–	–	3	–	–	–
Related Science and Technical Subjects (32 hrs.)									
Chem. 106, Gen. and Inorganic Chem.	4	–	4	–	–	–	–	–	–
Chemistry 225, Organic Chemistry	3	–	–	–	3	–	–	–	–
Chemistry 265, Prin. of Physical Chem.	4	–	–	–	–	4	–	–	–
Mat.-Met. Eng. 230, Thermo. I and 231, Lab	4	–	–	4	–	–	–	–	–
Mat.-Met. Eng. 250, Prin. of Eng. Materials	3	–	–	–	3	–	–	–	–
Eng. Mech. 211, Intro. to Solid Mech.	4	–	–	–	4	–	–	–	–
Elec. Eng. 314, Cct. Anal. and Electronics	3	–	–	–	–	–	–	–	3
Elec. Eng. 315, Cct. Anal. and Electronics Lab.	1	–	–	–	–	–	–	–	1
Science and Technical Electives	6	–	–	–	–	–	3	3	–
Program Subjects (31 hrs.)									
Chem. Eng. 330, Thermo. II	3	–	–	–	–	–	3	–	–
Mat.-Met. Eng. 351, Structure and Prop. of Mat.	4	–	–	–	–	4	–	–	–
Mat.-Met. Eng. 371, Physical Metallurgy	3	–	–	–	–	–	3	–	–
Mat.-Met. Eng. 450, Eng. Physical Ceramics	4	–	–	–	–	–	4	–	–
Mat. Met. Eng. 451, Intro. to High Polymers	4	–	–	–	–	–	–	4	–
Elect 2: Chem. Eng. 341(3), Mat.-Met. Eng. 455(3), 472(3)	6	–	–	–	–	3	–	3	–
Elect 2: 400 and 500 Departmental courses	7	–	–	–	–	–	–	4	3
Free Elective (4 hrs.)	4	–	–	–	–	–	–	–	4
Total	128	15	16	16	16	17	17	17	14

Requirements

Candidates for the degree Bachelor of Science in Engineering (Metallurgical Engineering)-B.S.E. (Met.E.)-must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms.

Courses	*Hrs.*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
		Term Enrolled							
Subjects required by all programs (58 hrs.)									
See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102—Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101—Graphics, and 102—Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	–	3	3
Humanities (0-6), Social Sciences (6-12) including Economics, and Related Subjects (0-6)	14	–	–	4	3	3	4	–	–
Advanced Mathematics (3 hrs.)									
Mathematics Elective	3	–	–	–	–	3	–	–	–
Related Science and Technical Subjects (32 hrs.)									
Chem. 106, General and Inorganic Chem.	4	–	4	–	–	–	–	–	–
Chem. 265, Prin. of Physical Chem.	4	–	–	–	–	4	–	–	–
Mat.-Met. Eng. 230, Thermo. I and 231, Lab.	4	–	–	4	–	–	–	–	–
Mat.-Met. Eng. 250, Prin. of Eng. Materials	3	–	–	–	3	–	–	–	–
Eng. Mech. 211, Intro. to Solid Mech.	4	–	–	–	4	–	–	–	–
Elec. Eng. 314, Cct. Anal. and Electronics	3	–	–	–	–	–	3	–	–
Elec. Eng. 315, Cct. Analy. and Electronics Lab.	1	–	–	–	–	–	1	–	–
Science and Technical Electives	9	–	–	–	–	–	3	3	3
Program Subjects (31 hrs.)									
Chem. Eng. 330, Thermo. II	3	–	–	–	–	–	3	–	–
Chem. Eng. 341, Rate Processes I	3	–	–	–	3	–	–	–	–
Mat.-Met. Eng. 351, Structure and Properties of Materials	4	–	–	–	–	4	–	–	–
Mat.-Met. Eng. 371, Physical Metallurgy	3	–	–	–	–	–	3	–	–
Mat.-Met. Eng. 489, Metallurgical Proc. Des.	4	–	–	–	–	–	–	4	–
Elect 2: Mat.-Met. Eng. 455(3), 472(3), 475(3)	6	–	–	–	–	3	–	3	–
Elect 2: 400 or 500 Departmental courses	8	–	–	–	–	–	–	3	5
Free Elective (4 hrs.)	4	–	–	–	–	–	–	–	4
Total	128	15	16	16	16	17	17	16	15

Applied Mathematics

Program Co-advisers: Professor Hadley J. Smith, 201 West Engineering; designated Mathematics adviser, 347 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. The core requirements include some flexibility to accommodate varying aptitudes and interests with respect to theory and practice. Each option contains additional mathematics which is directly related to its technical content.

Requirements

Candidates for the degree Bachelor of Science (Applied Mathematics)-B.S. (Appl. Math.)-must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms.

Courses	*Hrs.*	*Term Enrolled* 1	2	3	4	5	6	7	8
Subjects required by all programs (64 hrs.)									
See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216 or 286	16	4	5	4	3	–	–	–	–
Humanities 101 and 102—Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101—Graphics, and 102—Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	–	3	3
Humanities and Social Sciences	20	–	4	4	–	4	4	4	–
Core Requirements (29 hrs.)									
Math. 350, 450 or 451, 417, and Stat. 414	12	–	–	–	–	3	6	3	–
Eng. Mech. 218, Statics	3	–	–	3	–	–	–	–	–
Eng. Mech. 345, Dynamics	3	–	–	–	3	–	–	–	–
Elec. Eng. 215, Network Analysis	3	–	–	–	3	–	–	–	–
Elec. Eng. 320, Electromagnetics	4	–	–	–	–	4	–	–	–
Thermodyn.: e.g., Mech. Eng. 331 or Chem. 265	4	–	–	–	4	–	–	–	–
Technical Options (25-31 hrs.)									
Mathematics	9-15	–	–	–	–	–	–	3	6
Engineering and Science	16-22	–	–	–	–	3	6	3	4
Free Electives (4-10 hrs.)	4-10	–	–	–	3	3	–	–	4
Total	128	15	16	15	16	17	16	16	17

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.

Typical technical options are as follows:

Aeronautics		*Hours*
Math. 454, 473, 555		9
Eng. Mech. 319	4	
Aero Eng. 320, 330	7	
and two of 314, 414, 420, 441, 520	8	19
		28

Electrics		
Math. 454, 473, 555		9
Mat.-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
		25-28

Mechanics		
Math. 454, 473, 555		9
Two approved cognates in science or engineering, such as two of Chem. 266, Mat.-Met. Eng. 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
		26-28

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

Operations Research		
Math. 518, 554; Statistics 414		10
Sci. Eng. 340 or Eng. Mech. 326	8	
Elec. Eng. 420, 442	7	
Ind. Eng. 371, Ind. Eng. 441	6	21
		31
Physics		
Math. 454, 555, and one of Statistics 468, Math. 473, Physics 451		9
Elec. Eng. 380, 381, 420, Eng. Mech. 326	11	
Three of Physics 307, 402, 409, 453, 457	8-9	19-20
		28-29
Rate Processes		
Math. 448, 473, and one of 454, 571, 572		10
Mat.-Met. Eng. 250	3	
and one of the following sequences		
Chemical Engineering Sequence:		
Sci. Eng. 330, Chem. Eng. 341, 342, and two of 343, 407, 507, 508, 566, 588	17	
Mechanical Engineering Sequence:		
Eng. Mech. 326, Mech. Eng. 324, 336, 471	16	19-20
		29-30
Systems and Control		
Math. 473, 571 or 572, 594		9
Mat.-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	
Computer Information and Control Engineering Sequence:		
Math. 448, C.I.C.E. 482, 450, 451	11	
Industrial Engineering Sequence:		
Math. 554, Elec. Eng. 343, Ind. Eng. 472 and 441 or 541	13	20-22
		29-31
General Option		
Math. 454, 473, 555, and two of Statistics 414, Math. 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: Professor L. Quackenbush, 226 West 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 mass spectrometer and equipment for research in fluid amplifiers, chemical kinetics, gas dynamics, direct energy conversion, and lubrication.

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 cavitation and multiphase flow laboratory for theoretical and experimental investigations into many aspects of such phenomena; the automatic controls laboratory for demonstrating and investigating principles and applications of control systems; the combustion laboratory with a gas chromatograph and an infrared spectrometer; 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 metals, brittle fracture, heat treating, plasticity, friction and wear and surface phenomena. A well-equipped welding laboratory is also a part of the East Engineering complex.

Requirements

Candidates for the degree Bachelor of Science in Engineering (Mechanical Engineering)-B.S.E. (M.E.)-must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms.

Courses		*Term*	*Enrolled*						
	Hrs.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Subjects required by all programs (56 hrs.)									
See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102—Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101—Graphics, and 102—Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	–	3	3
Humanities and Social Sciences (to include a course in economics)	12	–	3	–	3	3	3	–	–
Advanced Mathematics (3 hrs.)									
Elective	3	–	–	–	–	3	–	–	–
Related Technical Subjects (17 hrs.)									
Mat.-Met. Eng. 250, Prin. of Eng. Materials	3	–	–	3	–	–	–	–	–
Eng. Mech. 211, Intro. to Solid Mechanics	4	–	–	4	–	–	–	–	–
Eng. Mech. 340, Intro. to Dynamics	4	–	–	–	4	–	–	–	–
Elec. Eng. 314, Cct. Anal. and Electronics	3	–	–	–	–	3	–	–	–
Elec. Eng. 315, Cct. Anal. and Electronics Lab	1	–	–	–	–	1	–	–	–
Elec. Eng. 442, Anal. of Electromechanical Devices	3	–	–	–	–	–	–	3	–
Program Subjects (36 hrs.)									
Mech. Eng. 251, Control of Mechanical Properties of Solids	3	–	–	–	3	–	–	–	–
Mech. Eng. 324, Fluid Mechanics	4	–	–	–	–	–	4	–	–
Mech. Eng. 335, Thermodynamics I	3	–	–	–	3	–	–	–	–
Mech. Eng. 336, Thermodynamics II	4	–	–	–	–	4	–	–	–
Mech. Eng. 340, Dynamics of Mechanical Sys.	4	–	–	–	–	–	4	–	–
Mech. Eng. 362, Mechanical Design I	3	–	–	–	–	3	–	–	–
Mech. Eng. 381, Manufacturing Proc.	4	–	–	–	–	–	4	–	–
Mech. Eng. 460, Mechanical Des.	3	–	–	–	–	–	–	3	–
Mech. Eng. 461, Automatic Control	4	–	–	–	–	–	–	–	4
Mech. Eng. 471, Transport of Heat and Mass	4	–	–	–	–	–	–	4	–
Technical Electives (12 hrs.)									
Including an advanced Mech. Eng. theory and an advanced Mech. Eng. laboratory course	12	–	–	–	–	–	3	3	6
Free Electives (3 hrs.)	3	–	–	–	–	–	–	–	3
Total	128	15	16	15	16	17	17	16	16

Meteorology and Oceanography

Program Advisers: Professor Dingle, 4082 East Engineering; Professor Epstein, 4072C East Engineering; Associate Professor Jacobs, 5510 East Engineering; Assistant Professor Monahan, 4072B 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, 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 meteorological 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 and Planetary Atmospheres 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 includes biological, chemical, geological and physical aspects of Oceanography.

Facilities

The Department of Meteorology and Oceanography includes laboratories for atmospheric turbulence and scintillation, cloud and precipitation physics, meteorological instrumentation, oceanography and submarine geology.

Requirements

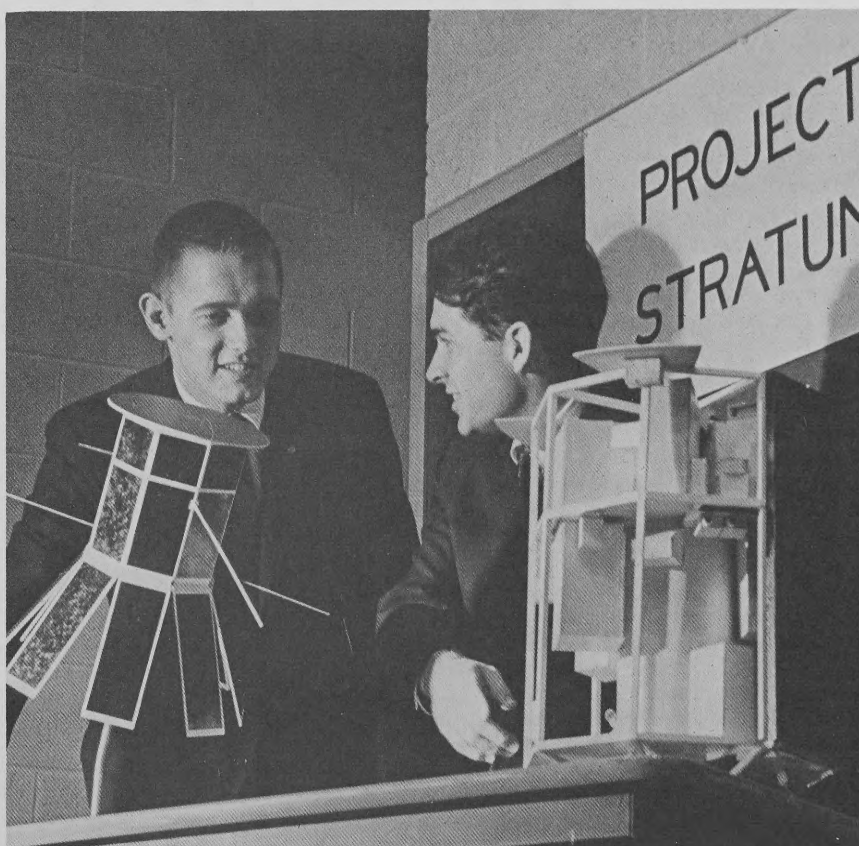
Candidates for the degree Bachelor of Science (Meteorology and Oceanography)-B.S. (Meteor. & Ocean.)-must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms:

Courses		*Term*	*Enrolled*						
	Hrs.	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
Subjects required by all programs (58 hrs.)									
See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102—Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101—Graphics, and 102—Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	–	3	3
Humanities and Social Sciences	14	–	–	4	4	3	3	–	–
Advanced Science (4 hrs.)									
Chem. 106, Gen. and Inorganic Chem.	4	–	4	–	–	–	–	–	–
Related Technical Subjects (16 hrs.)									
Eng. Mech. 340, Intro. to Dynamics	4	–	–	–	–	4	–	–	–
Eng. Mech. 326, Fluid Mechanics	4	–	–	–	–	–	4	–	–
Chem. 265, Princ. of Phys. Chem.	4	–	–	–	4	–	–	–	–
Elec. Eng. 314, Cct. Anal. and Electronics.	3	–	–	–	–	–	3	–	–
Elec. Eng. 315, Cct. Anal. and Electronics Lab.	1	–	–	–	–	–	1	–	–
Program Subjects (12 hrs.)									
M.&O. 304, Atmospheric and Oceanic Sciences I	3	–	–	3	–	–	–	–	–
M.&O. 305, Atmospheric and Oceanic Sciences II	3	–	–	–	3	–	–	–	–
M.&O. 306, Lab. in Geophysical Data I	2	–	–	2	–	–	–	–	–
M.&O. 307, Lab. in Geophysical Data II	1	–	–	–	1	–	–	–	–
M.&O. 331, Thermo. of Atmosphere and Oceans	3	–	–	–	–	–	3	–	–
Free Electives (4 hrs.)	4	–	–	–	–	–	–	–	4
Option I, Aeronomy and Planetary Atmospheres (34 hrs.)									
Mathematics 450, Adv. Math. for Eng. I	4	–	–	–	–	4	–	–	–
Physics 405, Intermediate Elect. and Magnetism	3	–	–	–	–	3	–	–	–
Physics 453, Atomic and Nuclear Phys. I.	3	–	–	–	–	–	3	–	–
Aero. Eng. 425, Prin. of Aerodynamics	3	–	–	–	–	–	–	–	3
M.&O. 332, Radiative Proc. in the Atmosphere	3	–	–	–	–	3	–	–	–
M.&O. 351, Geophysical Fluid Dynamics	3	–	–	–	–	–	–	3	–
M.&O. 464(Aero. Eng. 464), Aeronomy I	3	–	–	–	–	–	–	3	–
M.&O. 465(Aero. Eng. 465), Aeronomy II	3	–	–	–	–	–	–	–	3
Technical Electives	9	–	–	–	–	–	–	6	3
Total	128	15	16	17	15	17	17	15	16

Option 2, Meteorology (34 hrs.)									
Mathematics 450, Adv. Math. for Eng. I	4	–	–	–	–	4	–	–	–
M.&O. 312, Physical Climatology	3	–	–	–	–	–	3	–	–
M.&O. 332, Radiative Proc. in the Atmosphere	3	–	–	–	–	3	–	–	–
M.&O. 351, Geophysical Fluid Dynamics	3	–	–	–	–	3	–	–	–
M.&O. 411, Cloud and Precipitation Proc.	3	–	–	–	–	–	–	3	–
M.&O. 451, Atmospheric Dynamics I	4	–	–	–	–	–	–	–	4
M.&O. 454, Lab. in Weather Anal.	3	–	–	–	–	–	–	–	3
M.&O. 462, Meteorological Instrumentation	3	–	–	–	–	–	–	3	–
Technical Electives	8	–	–	–	–	–	–	8	–
Total	128	15	16	17	15	17	17	17	14
Option 3, Oceanography (34 hrs.)									
Geol. 218, Geology for Eng. (Note A)	3	–	–	–	–	3	–	–	–
Zool. 106, Intro. to Biology (Note A)	5	–	–	–	–	–	–	5	–
M.&O. 333, Physical Oceanography	3	–	–	–	–	3	–	–	–
Elective Sequence in Oceanography (12-15 hrs.)	13	–	–	–	–	–	3	3	7
(e.g. Biological, Chemical, Physical, Geological)									
Technical Electives (7-12 hrs.)	10	–	–	–	–	4	–	4	2
Total	128	15	16	17	15	17	17	15	16

Note A. Alternatives for Geol. 218: 111(4), 117(4). Alternate for Zool. 106: 101(4)



Naval Architecture and Marine Engineering

Program Adviser: Associate Professor Woodward, 445 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 conventional and nuclear steam plants, and the several types of internal combustion engines, 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.

Since the design of a modern ship encompasses many engineering fields, 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 others. These options are:

Option 1. Naval Architecture relates to the design of marine vehicles 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 vehicle 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.

Students may earn an additional B.S.E. degree in either aerospace engineering or industrial engineering under combined programs with the respective engineering departments. The programs allow substantial substitution of courses in one curriculum for those required in the other, and typically require one extra term to complete.

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 basin complete with shops and instrumentation is operated by the department for teaching and student and faculty research. The Department also operates a maneuvering and wave basin at the North Campus.

Requirements

Candidates for the degree Bachelor of Science in Engineering (Naval Architecture and Marine Engineering)-B.S.E.(Nav.Arch.&Mar.E.)-must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms.

Courses	Hrs.	*Term Enrolled* 1	2	3	4	5	6	7	8
Subjects required by all programs (56 hrs.)									
See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102–Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101–Graphics, and 102–Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	–	3	3
Humanities and Social Sciences	12	–	4	–	–	2	2	–	4
Advanced Mathematics (3 hrs)									
Elective	3	–	–	–	–	3	–	–	–
Related Technical Subjects (21 hrs)									
Mat.-Met. Eng. 250, Prin. of Eng. Materials	3	–	–	–	3	–	–	–	–
Eng. Mech. 211, Intro. to Solid Mechanics	4	–	–	4	–	–	–	–	–
Eng. Mech. 340, Intro. to Dynamics	4	–	–	–	4	–	–	–	–
Mech. Eng. 331, Thermodynamics I	4	–	–	–	4	–	–	–	–
Elec. Eng. 314, Cct. Anal. and Electronics	3	–	–	–	–	3	–	–	–
Elec. Eng. 315, Cct. Anal. & Electronics Lab	1	–	–	–	–	1	–	–	–
Eng. Mech. 403, Experimental Mechanics	2	–	–	–	–	–	2	–	–
Program Subjects (common to all options) (20 hrs)									
Nav. Arch. 200, Intro. to Practice	4	–	–	4	–	–	–	–	–
Nav. Arch. 400, Maritime Eng. Management	2	–	–	–	–	–	–	2	–
Nav. Arch. 420, Resistance, Propulsion & Propellers	4*	–	–	–	–	–	–	–	–
Nav. Arch. 310, Structural Design I	3	–	–	–	–	–	3	–	–
Nav. Arch. 330, Marine Engineering I	4	–	–	–	–	4	–	–	–
Nav. Arch. 331, Marine Engineering II	3	–	–	–	–	–	3	–	–
Option 1, Naval Architecture (28 hrs)									
Civ. Eng. 324(Eng. Mech. 324) Fluid Mech.	3	–	–	–	–	3	–	–	–
Mech. Eng. 337, Mech. Eng. Lab.	2	–	–	–	–	–	–	2	–
Nav. Arch. 300, Computer Techniques in Naval Architecture	2	–	–	–	2	–	–	–	–
Nav. Arch. 410, Stress Anal. of Ship Structures	3	–	–	–	–	–	–	–	3
Nav. Arch. 420, Resistance, Propulsion, & Propellers*	–	–	–	–	–	–	4	–	–
Nav. Arch. 440, Ship Dynamics	3	–	–	–	–	–	–	3	–
Nav. Arch. 446, Theory of Ship Vibrations I.	3	–	–	–	–	–	–	–	3
Nav. Arch. 470, Ship Design I	3	–	–	–	–	–	–	3	–
Nav. Arch. 475, Design Project	3	–	–	–	–	–	–	–	3
Technical Elective	3	–	–	–	–	–	3	–	–
Free Elective	3	–	–	–	–	–	–	3	–
Total	128	15	16	16	16	16	17	16	16

*Scheduled with options

Option 2, Marine Engineering (28 hrs)

Civ. Eng. 324(Eng. Mech. 324), Fluid Mechanics	3	–	–	–	–	3	–	–	–
Mech. Eng. 471, Transport of Heat & Mass	4	–	–	–	–	–	–	4	–
Elec. Eng. 442, Instrumentation	3	–	–	–	–	–	3	–	–
Nav. Arch. 420, Resistance, Propulsion & Propellers*	–	–	–	–	–	–	–	4	–
Nav. Arch. 431, Marine Engineering III	3	–	–	–	–	–	–	–	3
Nav. Arch. 446, Theory of Ship Variations I	3	–	–	–	–	–	–	–	3
Nav. Arch. 470, Ship Design I	3	–	–	–	–	–	–	3	–
Nav. Arch. 475, Design Project	3	–	–	–	–	–	–	–	3
Technical Elective	3	–	–	–	–	–	3	–	–
Free Elective	3	–	–	–	3	–	–	–	–
Total	128	15	16	16	17	16	16	16	16

Option 3, Maritime Engineering Science (28 hrs)

Eng. Mech. 326, Fluid Mechanics	4	–	–	–	–	4	–	–	–
Nav. Arch. 420, Resistance, Propulsion & Propellers*	–	–	–	–	–	–	4	–	–
Nav. Arch. 490, Directed Study, Research and Special Problems	3	–	–	–	–	–	–	–	3
Technical Electives (Note A)	18	–	–	–	–	–	3	10	5
Free Elective	3	–	–	–	3	–	–	–	–
Total	128	15	16	16	17	17	17	15	15

Note A: Must include 6 hours of naval architecture and 6 hours of mathematics, and at least 12 hours must be selected from:

	Hours
Nav. Arch. 300, Form Calculations and Static Stability II	2
Nav. Arch. 410, Stress Anal. of Ship Structures	3
Nav. Arch. 440, Ship Dynamics	3
Nav. Arch. 446, Theory of Ship Vibrations I	3
Nav. Arch. 470, Ship Design I	3
Math. 448, Operational Methods for Sys. Anal.	4
Math. 450, Adv. Math. for Eng. I	4
Math. 473, Intro. to Digital Computers	3
Math. 552, Fourier Series and Applications	3
Math. 554, Adv. Math. for Eng. II	4
Math. 555, Intro. to Functions of a Complex Variable with Applications	3
Math. 557, Intermediate Course in Differential Equations	3
Ind. Eng. 472, Operations Research	3
Mech. Eng. 471, Transport of Heat and Mass	4
Nuc. Eng. 400, Elements of Nuc. Eng.	3
Eng. Mech. 412, Intermediate Mech. of Materials	3
Eng. Mech. 422, Intermediate Mech. of Fluids	3
Eng. Mech. 442, Intermediate Dynamics	3
Aero. Eng. 425, Prin. of Aerodynamics	3
C.I.C.E. 450, Feedback Control I	3
C.I.C.E. 451, Feedback Control Laboratory I	1
C.I.C.E. 482, Applic. of the Analog Computer	3

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 reactions and radioactive decay. 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) Nuclear reactor engineering including reactor theory, reactor design applications and nuclear power plant analysis.

b) Radiation effects including radiation detection, radiation damage and nuclear measurements in medicine.

c) Neutron scattering methods in the study of materials.

d) Theoretical and experimental plasma physics and thermonuclear theory.

e) Radiation transport theory and applications.

f) Fluid flow and heat transfer phenomena related to reactor problems.

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

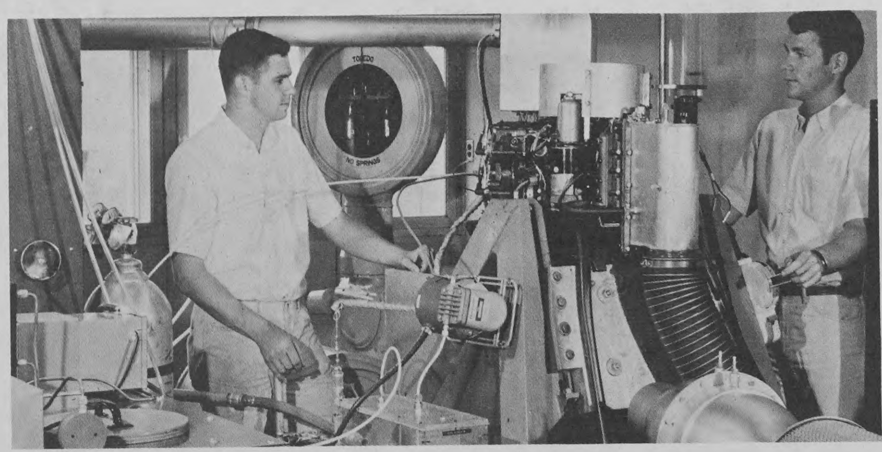
Special facilities available to nuclear engineering students include the following:
2 megawatt swimming pool research reactor
Subcritical assembly and Sigma pile
Analog computer
Single axis crystal neutron spectrometer and single rotor chopper
Triple axis crystal neutron spectrometer
Four rotor phased 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
Moessbauer spectrometer

Requirements

Candidates for the degree Bachelor of Science in Engineering (Nuclear Engineering)-B.S.E. (N.E.)-must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms.

Courses	*Hrs.*	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*
		Term Enrolled							
Subjects required by all programs (62 hrs.)									
See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102—Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101—Graphics, and 102—Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	3	–	3
Humanities and Social Sciences (to include Economics 400)	18	–	4	4	3	3	–	4	–
Advanced Mathematics and Science (10 hrs.)									
Math. 404, Differential Equations	3	–	–	–	–	3	–	–	–
Math. 450, Adv. Math. for Eng. I	4	–	–	–	–	–	4	–	–
Phys. 242, Gen. Phys. III	3	–	–	–	3	–	–	–	–
Related Technical Subjects (15 or 14 hrs.)									
Mat.-Met. Eng. 250, Princ. of Eng. Materials	3	–	–	3	–	–	–	–	–
Eng. Mech. 340, Intro. to Dynamics or Phy. 401, Intermed. Mech. (3)	4	–	–	–	–	4	–	–	–
Mech. Eng. 331, Classical & Statistical Thermodyn.	4	–	–	–	4	–	–	–	–
Elec. Eng. 314, Cct. Anal. and Electronics	3	–	–	–	–	3	–	–	–
Elec. Eng. 315, Cct. Anal. and Electronics Lab.	1	–	–	–	–	1	–	–	–
Program Subjects (25 hrs.)									
Nuc. Eng. 311, Elements of Nuc. Eng. I	3	–	–	–	–	3	–	–	–
Nuc. Eng. 312, Elements of Nuc. Eng. II	3	–	–	–	–	–	3	–	–
Nuc. Eng. 315, Nuc. Instr. Lab.	4	–	–	–	–	–	4	–	–
Nuc. Eng. 441, Fiss. Reactors and Powerplants I	3	–	–	–	–	–	–	3	–
Nuc. Eng. 442, Fiss. Reactors and Powerplants II	3	–	–	–	–	–	–	–	3
Nuc. Eng. 471, Plasmas and Controlled Fusion I	3	–	–	–	–	–	–	3	–
Nuc. Eng. elective	3	–	–	–	–	–	–	–	3
Nuc. Eng. laboratory (above Nuc. Eng. 315)	3	–	–	–	–	–	–	–	3
Technical Electives (10 or 11 hrs.)	10	–	–	–	–	–	3	3	4
Free Electives (6 hrs.)	6	–	–	–	3	–	–	3	–
Total	128	15	16	15	16	17	17	16	16



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 Bachelor of Science in Engineering (Physics)-B.S.E. (Phys.)-must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms.

Courses	Hrs.	*Term Enrolled* 1	2	3	4	5	6	7	8
Subjects required by all programs (58 hrs.)									
See under "Variations" for alternatives									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102–Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101–Graphics, and 102–Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	3	–	3
Humanities and Social Sciences	14	–	–	4	7	3	–	–	–
Advanced Mathematics and Science (11 hrs.)									
Chem. 106, Gen. and Inorganic Chem.	4	–	4	–	–	–	–	–	–
Math. 450, Adv. Math. for Eng. I	4	–	–	–	–	–	4	–	–
Math. elective	3	–	–	–	–	–	–	3	–
Related Technical Subjects (14 hrs.)									
Eng. Mech. 211, Intro. to Solid Mech.	4	–	–	4	–	–	–	–	–
Mat.-Met. Eng. 250, Prin. of Eng. Materials	3	–	–	–	–	3	–	–	–
Elec. Eng. 211, Resistive Network Anal.	2	–	–	–	2	–	–	–	–
Elec. Eng. 300, Math. Methods in Sys. Anal.	3	–	–	–	–	3	–	–	–
Elec. Eng. 311, Dynamic Network Analysis	2	–	–	–	–	2	–	–	–
Program Subjects (26 hrs.)									
Physics 401, Intermediate Mechanics	3	–	–	–	3	–	–	–	–
Physics 405, Intermediate Electricity and Mag.	3	–	–	–	–	3	–	–	–
Physics 406, Heat and Thermodynamics	3	–	–	–	–	–	3	–	–
Physics 411, Mechanics of Fluids	3	–	–	–	–	3	–	–	–
Physics 453, Atomic and Nuc. Physics I	3	–	–	–	–	–	–	3	–
Physics 455, Electron Tubes	4	–	–	–	–	–	–	4	–
Physics Electives	7	–	–	–	–	–	–	3	4
Technical Electives–Engineering Sequence (12 hrs.)	12	–	–	–	–	–	4	4	4
Free Electives (7 hrs.)	7	–	–	–	–	–	3	–	4
Total	128	15	16	16	15	17	17	17	15

Science Engineering

Program Adviser: Professor A. F. Messiter, Jr., 1520 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. Alternatively, 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, bio-engineering, 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 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 Bachelor of Science in Engineering (Science Engineering)-B.S.E. (Sci.E)-must complete the following program:

Schedule below is an example of one leading to graduation in 8 terms.

Courses	*Hrs.*	*Term Enrolled* 1	2	3	4	5	6	7	8
I. Subjects required by all programs (58 hrs.) *See under "Variations" for alternatives*									
Mathematics 115, 116 and 117, 215, and 216	16	4	5	4	3	–	–	–	–
Humanities 101 and 102—Great Books I and II	6	3	3	–	–	–	–	–	–
Engineering 101—Graphics, and 102—Computing	4	4	–	–	–	–	–	–	–
Chemistry 103 or 104	4	4	–	–	–	–	–	–	–
Physics 140 with Lab. 141; 240 with Lab. 241	8	–	4	4	–	–	–	–	–
Literature and Rhetoric	6	–	–	–	–	–	–	3	3
Humanities and Social Sciences	14	–	4	3	7	–	–	–	–
II. Advanced Mathematics and Science (13 hrs.)									
Electives in advanced mathematics, chemistry, physics, and thermodynamics	13	–	–	–	–	4	3	3	3
III. Related Technical Subjects (34 hrs.) Note A									
Eng. Mech. 218, Statics	3	–	–	3	–	–	–	–	–
Eng. Mech. 345, Dynamics	3	–	–	–	3	–	–	–	–
Eng. Mech. 319, Mechanics of Solids I	4	–	–	–	–	4	–	–	–
Eng. Mech. 326, Fluid Mechanics	4	–	–	–	–	–	4	–	–
Elec. Eng. 215, Network Analysis	3	–	–	–	3	–	–	–	–
Elec. Eng. 320, Electromagnetics	4	–	–	–	–	4	–	–	–
Elec. Eng. 337, Electronic Ccts. and Sys.	4	–	–	–	–	–	4	–	–
Materials, e.g. Mat.-Met. Eng. 250 (3 hrs.)	3	–	–	3	–	–	–	–	–
Thermodynam., e.g. Mech. Eng. 331 (4 hrs.)	4	–	–	–	–	4	–	–	–
Rate Proc., e.g. Sci. Eng. 340 (4 hrs.)	4	–	–	–	–	–	4	–	–
IV. Engineering Electives (17 hrs.) Note A	15	–	–	–	–	–	–	8	7
V. Free Electives (6 hrs.)	6	–	–	–	–	–	–	3	3
Total	128	15	16	17	16	16	15	17	16

Note A. The recommended Eng. Mech. sequence shown here includes 2 hrs. beyond the 12 hour minimum, which can be used under Engineering Electives, as shown above.

Definitions, Recommendations and Options. The courses in Group I represent minimum hour requirements established by the College of Engineering and must be completed, or the equivalent proficiencies must be demonstrated. Among these subjects, the Unified Science sequence of accelerated and integrated, preparatory courses are strongly recommended for those students who are qualified. Those students who pursue chemistry beyond 104 (4) may use any additional credit hours involved for credit under the Group II science electives.

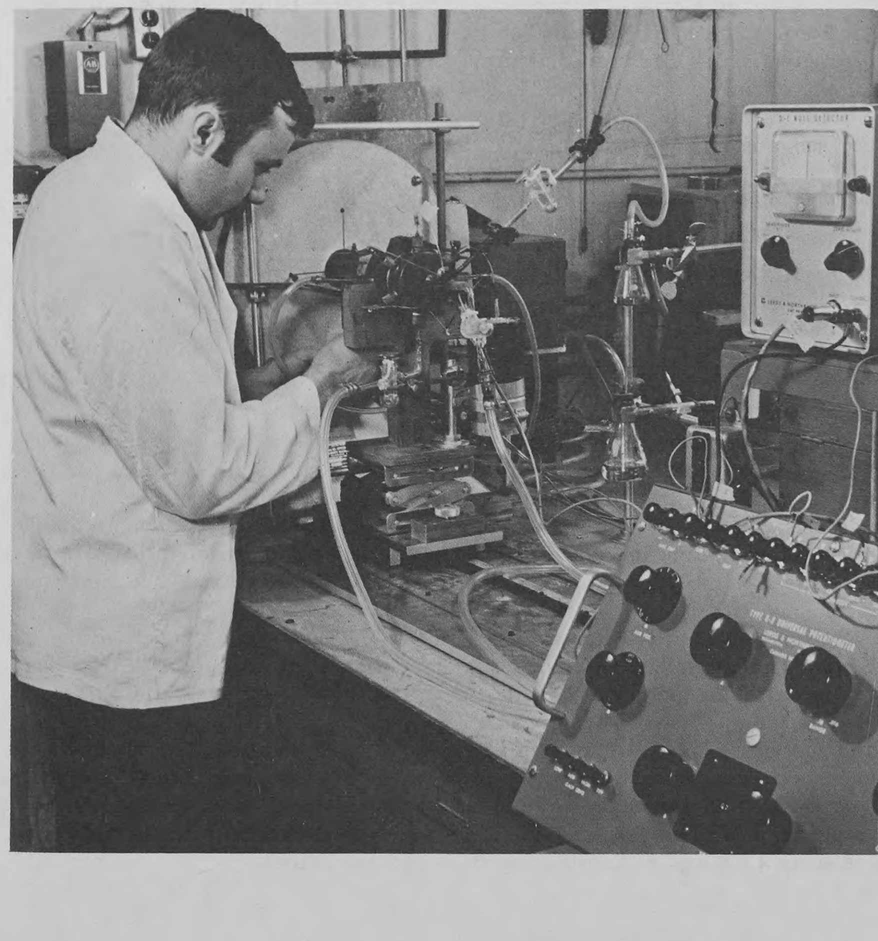
For example, Chemistry 106 (4) is especially recommended for a student not taking honors chemistry, who desires to pursue the advanced chemistry courses necessary to specialization in fields such as Chemical, Metallurgical, or Bio-engineering.

For the engineering science courses under Group III, the special sequences consisting of Eng. Mech. 218 (3), 345 (3), 319 (4) and 326 (4), Elec. Eng. 215 (3), 320 (4), and 337 (4), and Sci. Eng. 340 (4) are normally recommended. These have been developed by the respective departments especially for the Science Engineering Program, and are among the most effective and challenging courses in their respective subject areas. The two additional hours of engineering mechanics in the above sequence, beyond the minimum specified under Group III, may be used as elective credit in the Group IV or V electives. The preferred course in thermodynamics is Mech. Eng. 331 (4), and the course recommended for the materials requirement is Mat.-Met. Eng. 250 (3).

With the approval of the program adviser, certain equivalent courses may be substituted for the Group III courses listed above, when it is deemed advantageous in developing a program to meet the special interests of individual students.

The electives in Group V should reflect an effort to obtain a meaningful breadth or concentration in one of the various technical or non-technical elective areas cited above. Also acceptable in this category are four credit hours of advanced courses in air, military, or naval science (300 or 400 series), for students who complete one of the Military Officer Education Programs.

Elective Sequences. In addition to most of the engineering fields and options, with degree programs described in this Announcement, there are lists available on request of recommended course sequences leading to concentration and/or preparation for graduate work in such areas as: Bioengineering, Business Adminstration, Chemistry, Communications Science, Computer Information and Control Engineering, Heat Transfer and Thermodynamics, Industrial Engineering, Law, Medicine, Physics, and Radio Astronomy.



Military Officer Education Program

The University cooperates with the armed Services of the United States in providing an opportunity for each student who so desires to earn a commission in one of the three services—Army, Navy, and Air Force—upon completion of his degree requirement. (The Air Force enrolls both male and female students). The opportunity is available through voluntary enrollment in the Military Officer Education Program. (Nationally, the Reserve Officers Training Corps).

The Program provides a system of instruction in essential military subjects. The graduates constitute an important source of the officers needed for the Army, Navy (including Marine Corps), and the Air Force.

A significant feature of the Program is the recognition of the important contribution that certain elected or specified University courses make to the education of a military officer. Each such course substitution results in a reduction of time needed for courses required by the Program of the respective unit.

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 as follows for further information:
Army—Chairman of the Army Officer Education Program;
Navy or Marine Corps—Chairman of the Navy Officer Education Program;
Air Force—Chairman of the Air Force Officer Education Program.

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, the student should refer to the Chairman of his Program.

Army Officer Education Program

Colonel Schiller, Chairman; Major Radike, Captain Shoemaker, Captain Steelman, and Captain Ziegler.

Program Office: Room 127 North Hall

A student desiring to earn a Commission in the U.S. Army would volunteer to enroll in the Army Officer Education Program in Military Science—hereinafter referred to as the Program.

General Information. The objective of the 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. Graduates, after attaining a baccalaureate degree, are commissioned as Second Lieutenants in the Army Reserve. Outstanding 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 Basic Course with the permission of the Chairman of the Program. Enrollment is elective for the first two years which comprise the Basic Course. The freshman and sophomore years are a combination of MS 101 and 102, MS 201 and 202, and selected university courses which are regularly scheduled. These university courses must be completed prior to entry into the Advanced Course. A cadet may drop a Military Science Basic Course (100 or 200 series) in accordance with the current College of Engineering rules and procedures.

Entrance into the Advanced Course (MSIII and MSIV 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 Course he must have completed the Basic Course (MSI and MSII years) or six weeks basic training camp in the term between the sophomore and junior years at an Army Basic Training Camp. These cadets who desire to enter the Advanced Course by attendance at the six weeks summer camp should contact the Chairman of the Program as soon as possible after 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 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.

Advanced Standing. Students with prior military service or prior ROTC training (high school or college) may receive advanced standing. Transfer students from colleges without 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 Chairman of the Program personally for advanced standing determination. Students who desire to qualify for advanced standing by attendance at summer training should contact the Chairman as soon as possible after the beginning of the winter term.

Military Obligation. Upon commissioning, or after completion of an advanced degree, the current military obligation is as follows:

Non-scholarship program—two years active duty and four years in the reserve;

Scholarship programs (see below)—four years active duty and two years in the reserve.

Current changes in the active duty obligation for non-scholarship programs may provide selected individuals with an alternative of up to six months active duty and a total of eight years in the reserve.

Academic Delay. 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 and may be renewed for three years or longer if necessary. University of Michigan graduates have received a very high approval rate for such applications; however, individual cases must continue to be determined with appropriate consideration for the active duty requirements of the service.

Scholarship Programs. 1) Four-year Scholarship Program: This program is open to freshmen students on a competitive basis. Application is made during the second half of the senior high school year. Application procedures are announced in the early spring of each year to high school seniors. The scholarships are awarded based upon high school academic records, scholastic aptitude tests, personal observation, physical examination, and interview. This scholarship provides for fees, textbooks, classroom materials, lab fees, and $50 per month for four years.

2) Three-year Scholarship Program: To apply for this program a student must have completed Military Science 101 and 102. This scholarship provides for fees, textbooks, classroom materials, lab fees, and $50 per month for the three years.

3) Two-year Scholarship Program: To apply for this program a student must satisfactorily complete on campus the Basic Course, (first two years), and be accepted by the Chairman of the Program for enrollment in the advanced course. This scholarship provides for fees, textbooks, classroom materials, lab fees, and $50 per month for the MSIII and MSIV years.

4) One-year Scholarship Program: To apply for this Program, a student must have completed the Basic Course (two years) and the MSIII year of the advanced course. This scholarship provides for fees, textbooks, classroom materials, lab fees, and $50 per month for the Military Science IV year.

Flight Program. Qualified MSIII 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 MSIV year, cadets will be classified for branch assignments upon commissioning to one of fifteen branches in accordance with their preference, aptitude, curriculum, interest, physical condition, and the worldwide needs of the Army. Branches in which a cadet may be commissioned are as follows: Armor, Field Artillery, Air Defense Artillery, Adjutant General's Corps, Military Intelligence, Chemical Corps, Corps of Engineers, Finance Corps, Infantry, Medical Service Corps, Military Police Corps, Ordnance Corps, Quartermaster Corps, Signal Corps, and Transportation Corps.

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 one-half of the basic pay of a second lieutenant 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 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 MSIII 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).

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: (1) the Defense Establishment and National Security; (2) Tactical Planning and Operations; (3) Leadership Development; (4) School of the Soldier and Exercise of Command (Leadership Laboratory). Additionally, a minimum of four university courses are required as academic substitution on a schedule to be determined by the Chairman of the Program. The instructional objective of the Program of Military Science is to integrate the instruction into a progressive development of self confidence, initiative, sense of responsibility, high moral standards, leadership, and management skills.

101. U.S. Defense Establishment I. *Prerequisite: Permission.*
Instruction on organization of the Army and ROTC and the military as a profession; marksmanship training; growth and development of the Army.

102. U.S. Defense Establishment II. *Prerequisite: MS 101 and permission.*
Instruction on growth and development of the Army and the Defense Establishment in National Security; leadership laboratory.

201. Introduction to Tactics and Operations I. *Prerequisite: MS 102 and permission.*
Map and aerial photograph reading; duties and responsibilities of junior leaders.

202. Introduction to Tactics and Operations II. *Prerequisite: MS 201 and permission.*
Instruction on basic tactics and planning; the Advanced Course; leadership laboratory. Leadership laboratory is designed to give sophomores opportunity to develop leadership potential with view toward selection into Advanced Course by Army staff.

301. Leadership and Management I. *Prerequisite: MS 101, 102, 201, 202, specified academic substitution courses, and selection; or successful completion of ROTC basic camp, and selection. (2).*
Motivational factors which affect human behavior and leadership; developing individual presentations; and leadership development. Leadership development is designed to identify and illustrate effective leadership methods, provide the student opportunities to apply leadership and management techniques, and develop the student's proficiency in making formal and informal presentations.

302. Fundamentals and Dynamics of the Military Team I. *Prerequisite: 301 and permission. (2).*
Small unit tactics and communications; branches of the Army; leadership development. Leadership is a continuation of MS 301.

401. Leadership and Management II. *Prerequisite: MS 302 and permission. (2).*
Instruction on coordination and planning for the military team (command and staff procedure, logistics, intelligence and operations); leadership and management (administrative management, Army readiness program and military law); combat operations; the obligations and responsibilities of an officer.

402. Fundamentals and Dynamics of the Military Team II. *Prerequisite: MS 401 and permission. (2).*
Leadership laboratory designed to allow cadets to function as assistant instructors and cadet unit leaders in the MS 300 series leadership laboratories prior to functioning as commissioned officers on active duty. Forty-five class hours of academic substitution from a list of university courses taught regularly. The academic substitution course must be completed prior to commissioning.

Navy Officer Education Program

Colonel Hannah, Chairman; Commander Hurd, Major Doman, Lt. Goldstein, Lt. Hart, and Lt. Lett

Program Office: Room 100 North Hall

A student desiring to earn a Commission in the U.S. Navy or Marine Corps would volunteer to enroll in the Navy Officer Education Program in Naval Science—hereinafter referred to as the Program.

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

Objectives. The major goals of the Program are:

1) To assist in the education of the midshipman in a major field of study of interest to the Navy or Marine Corps leading to a baccalaureate degree.

2) To provide the midshipman with the fundamental concepts and principles of Naval Science and with the professional Naval knowledge necessary to establish a sound basis for his future growth as a Naval or Marine Corps officer.

3) To prepare the midshipman for service with the highest sense of honor and integrity as a commissioned officer; to cultivate the essential elements of military leadership; and to foster the growth of a strong sense of loyalty and dedication to this service and to the Nation.

4) To prepare the midshipman to undertake successfully in later periods of his career, advanced/continuing education in a field of application and interest to the Naval Service.

5) To inject the values of civilian higher education into the Naval Service by utilizing the expertise of civilian faculty instruction where applicable.

Officer Candidates. The Program provides two opportunities: a four-year Scholarship program with financial assistance and a four year Non-scholarship program (College Student Program) without financial assistance (excluding retainer pay, as described below).

The financially assisted Scholarship program provides for those eligible and selected to receive assistance for a period up to four years to include all tuition, fees, books, and laboratory expenses. Midshipmen also are provided with uniforms required for participation and receive retainer pay at the rate of $50 per month. Selection for this program is accomplished through nation-wide competition. Further Information can be obtained from the Program office.

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

Students entering the four year Scholarship program enter the Naval Reserve until commissioning. Those students entering the four-year Non-scholarship program enlist in the Naval Reserve for the last two years of their training. Those students who make every attempt to fulfill their contract but are disenrolled from the program will be released from their enlisted reserve status if they so choose.

Requirements

1) The following Naval Science course requirements must be met by all candidates prior to receiving a commission:

	Term I		*Term II*	
Freshmen	NS 101 plus Lab/Seminar	3 hrs/wk 1 hr/wk	NS 102 plus Lab/Seminar	3 hrs/wk 1 hr/wk
Sophomores	Lab/Seminar	2 hrs/wk	Lab/Seminar	2 hrs/wk
Juniors	NS 301 or NS 305* plus Laboratory	3 hrs/wk 2 hrs/wk	NS 302 or NS 306* plus Laboratory	3 hrs/wk 2 hrs/wk
Seniors	NS 401 or NS 405* plus Laboratory	3 hrs/wk 1 hr/wk	NS 402 or NS 406* plus Laboratory	3 hrs/wk 1 hr/wk

* Marine option candidates

2) All Scholarship students are required to complete three summer-at-sea training periods. These training periods are approximately six weeks in duration each and are taken between the Freshman-Sophomore, Sophomore-Junior, and Junior-Senior years.

3) All Non-scholarship students are required to complete one summer-at-sea training period of approximately six weeks in duration. Normally, this cruise is taken between the Junior-Senior year.

4) All Scholarship and Non-scholarship students are required to complete the following University offered courses in addition to the Naval Science courses indicated above, prior to commissioning:

Engineering, Physics, Chemistry or Math Students		*Arts, Humanities, Business, Political Science or Economics Students*	
Courses	*Credits*	*Courses*	*Credits*
Calculus	6–8	Calculus (preferrred) or Statistics and Probability*	6–8
Physics or Chemistry	6–8	Physics or Chemistry (pref.) or Biological/ Earth Sciences	6–8
Computer Science†	3–4	Computer Science‡	3–4
History (as selected by History Dept. and Unit)	3–4	History (as selected by History Dept. and Unit)	3–4
Political Science (as selected by Political Science Dept. and Unit)	3–4	Political Science (as selected by Political Science Dept. and Unit)	3–4

Courses Offered by the Naval Science Department

The courses listed herein are offered primarily for the Scholarship and Non-scholar-

* Statistics 300—Introduction to Probability (3) offered by the School of Business Administration recommended.

† For Engineering students, Engineering 102, Elementary Computer Techniques will satisfy this requirement.

‡ Introduction to Computer Processing Systems 311 (2) offered by the School of Business Administration will satisfy this requirement.

ship students; however, they are open to and may be taken by any University enrolled student with prior permission of the Naval Science instructor.

101. Introduction to Naval Science. *(3).*
An introduction to the structure and principles of naval organization and management. Naval organization and management practices and the concepts that lie behind them are examined within the context of American social and industrial organization and practice. It includes lines of command and control, organization for logistics, service and support, functions and services of major components of the Navy and Marine Corps, and shipboard organization. Emphasis is placed on management and leadership functions.

102. Introduction to Naval Ships Systems. *Prerequisite N.S. 101. (3).*
A course designed to familiarize midshipmen with the types, structures, and purpose of naval ships. Ship compartmentation, propulsion systems, auxiliary power systems, interior communications, and ship control are included. Elements of ship design to achieve safe operations, and ship stability characteristics are examined.

301, 302. Navigation and Naval Operations I and II. *(3).*
A comprehensive study of the theory, principles and procedures of ship navigation, movements, and employment. Course includes spherical trigonometry, mathematics analysis, study and practices, spherical triangulation, sights, sextants and publications and report logs. Tactical formations and dispositions, relative motion, maneuvering board, tactical plots are analyzed for force of affectiveness and unity. Rules of the road, lights, signals and navigational aids including inertial systems. A practice laboratory of 30 hours each term complements the classroom presentations.

305. Study of Evolution of Art of War. *(3).*
For Marine Corps option candidates. Analysis of decisive battles of history according to the principles of war and evolution of weapons.

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

401. Naval Weapons Systems I. *(3).*
The concept of weapons systems and the systems approach are explored. The techniques of linear analysis of ballistics and weapons are introduced. The dynamics of the basic components of weapons control systems are investigated and stated as transfer functions. This course provides the tools for the further development in the student understanding of the basic principles that underlie all modern naval weapons systems.

402. Naval Management. *Prerequisite: N.S. 401. (3).*
An introduction to naval organization management and study of leadership problems of particular interest to the junior officer. The course will also deal with the Navy directive system, professional periodicals and administrative practices of the Naval service, communications systems and correspondence procedures will be discussed as they pertain to administration. Pre-commissioning details and active duty orientation will also be accomplished throughout the term.

405. Amphibious Warfare I. *(3).*
For Marine Corps option candidates. The history, development, and techniques of amphibious warfare.

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

Air Force Officer Education Program

Lieutenant Colonel Bevivino, Chairman; Major Jones, and Captain Christen.

Program Office: Room 154 North Hall.

A student desiring to earn a Commission in the U.S. Air Force would volunteer to enroll in the Air Force Officer Education Program in Air Science—hereinafter referred to as the Program.

General Information. The Program includes studies designed to prepare selected male and female 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, projected, and historical Aeronautical and Astronautical efforts, 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.

There are two alternative plans of study: a four-year and a two-year plan. The four-year plan comprises eight terms of Air Science courses on campus plus a four-week field training course at an active Air Force base between the sophomore and junior years. The two-year plan comprises an initial six-week field training course followed by A.S. 300 and 400 on campus. Students may be enrolled in either the four-year or the two-year program. A limited number of Air Force scholarships, covering full University fees, a book allowance, and a monthly subsistence allowance, are available on competitive basis for cadets in the four-year program only.

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 25 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 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 30th birthday, may enroll in the four-year Program on a nonscholarship basis. Students enrolled in the University, or transfer students interested in the two-year program, should contact the Chairman of the Program, as early as possible before 10 November prior to the desired fall enrollment to schedule attendance at a 6-week Field Training Course conducted at an Air Force base during the summer prior to enrollment as a cadet. Students with prior military service may enroll above the entry level, based upon evaluation of such military service by the Chairman.

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 Chairman of the Program. They should contact the Chairman prior to registration week, if possible, in order that a tentative determination of eligibility may be made, and to allow time 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 any Air Science 100 or 200 series course may drop at any time allowed by the general rules of the college. When a student enters the advanced program (Air Science 300 and 400 series—except 403 when taken as a non-Air Force student), he assumes a contractual obligation to complete the program, accept a commission, and serve on active duty as an officer.

Scholarships and Monetary Allowances. Freshmen may apply for three year, and sophomores for two year scholarships. Each scholarship provides all tuition and laboratory fees, a book allowance, plus $50 per month subsistence allowance. Advanced cadets (third and fourth Air Science years) who are not on Air Force scholarships also receive the 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 the uniform is returned or becomes a gift of the University.

Commissions in the Air Force. Cadets completing the Program and receiving a baccaulaureate 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. (Women students may not seek Flight Duties within the Air Force, nor certain other types of duty such as police duty.) 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.

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.

Course Substitution. Portions of the Air Science courses listed below may be completed by substitution of existing catalogue listed courses offered by the various colleges with the approval of the Chairman of the Program and the student's college counselor. Engineering students usually find the use of course substitution results in reduced workload and concentration of course choices more closely to basic degree objectives while still completing the Air Science curriculum. When substitution is used, corresponding portions of the Air Science courses are not required.

Courses Offered in Air Science

101. World Military Systems. I. *(1).*
Lecture, 1 hour a week; Cadet Corps activities, 1 hour a week.
Mission, doctrine and organization of the USAF; mission, organization and functions of general purpose forces and tactical air 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.
U.S. strategic offensive and defensive forces; fundamentals of military procedures.

201. World Military Systems. I. *(1).*
Lecture, 1 hour a week; Cadet Corps activities, 1 hour a week.
Nature and principles of war; defense organization. U.S. general purpose forces; Development of leadership ability.

202. World Military Systems. II. *(1).*
Lecture, 1 hour a week; Cadet Corps activities, 1 hour a week.
Comparative Defense Policies; alliances and collective security; 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; 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. Air Force Leadership and Management. 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. Air Force Leadership and Management. 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. Pilot Ground School. I,II. *(1).*
Lecture/practicum, 3 hours a week for 9 weeks, by arrangement.
Preflight, meteorology, Federal Aviation Regulations, flight computer, navigation, radio navigation. (Required by all participants in the Flight Instruction Program. Such participants must enroll in both A.S. 401 and A.S. 403.) Open to all University students with approval of instructor.

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.

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.

Anyone contemplating graduate work should consult with the program adviser or the advisory committee for the desired program. The College is offering a variety of graduate level courses via closed circuit television into the greater Detroit area for credit. The remote student participates directly in the on-campus classroom presentations.

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 mathematics or an appropriate field of physical science are offered opportunities by the faculty of the College of Engineering in several instances to pursue their studies 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 adviser or advisory committee for the program elected, with an average grade of at least B covering all courses elected as a graduate student.

It is required that a student take at least two graduate-level cognate courses for a minimum of two hours of credit each in a department other than the department of his specialization, selected with the approval of his adviser.

A 400-level course listed in the Announcement of the Horace H. Rackham School of Graduate Studies may be elected for graduate credit when approved by the student's adviser.

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 and Planetary Atmospheres

Advisory Committee: Professors Epstein and Jones, Associate Professors Bartman, and Nagy, Assistant Professors Drayson and Kuhn, Lecturer Fontheim

An interdepartmental Master of Science program in Aeronomy and Planetary Atmospheres is offered for graduates adequately prepared in mathematics and physics. It encompasses the physics and dynamics of the atmospheres of the earth and planets, and requires courses in both theoretical and experimental aspects of space science. Several laboratories provide opportunities for student participation in active research.

The program includes Elec. Eng. 495 (3) and Meteor.-Ocean. 564 (3) and at least nine hours from the following list: Aero. Eng. 464 (Meteor.-Ocean. 464); Aero. Eng. 465; Aero. Eng. 466; Meteor.-Ocean. 532; Meteor.-Ocean. 533; Meteor.-Ocean. 565; Elec. Eng. 595; Aero. Eng. 596; and Aero. Eng. 895 (Elec. Eng. 895).

The remainder of the program shall consist of appropriate cognate subjects, as approved by one of the graduate advisers, usually selected to augment the student's background as necessary in the relevant physical sciences and mathematics.

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

Advisory Committee: consult departmental office

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. in Bioengineering

Adviser: Professor G. V. Edmonson, 207 West Engineering

A new graduate educational opportunity is being offered to qualified students to prepare for participation in a recently recognized engineering activity, Bioengineering. Educational programs are jointly supported by the College of Engineering and the Medical School leading to both masters and doctors degrees; they are designed for the student who finds a challenge in seeking solutions to engineering problems presented by the performance of living systems. The engineer finds many opportunities to apply analytical methods. He will study a related sequence of topics involving the medical, engineering, and behavioral sciences and will continue to extend his technological training.

There are many sub-systems of the living system which may be better understood through use of the analytical methods of engineering. All living systems are controlled; therefore, the technology of control is applicable. The physical properties of tissue bear the same importance to the living system that the properties of non-living materials do to physical systems. The science of materials is, likewise, applicable. The chemical, mass transport, electrical, and mechanical properties of these systems combine in a very complex, yet ordered, manner to cause their continuing function. Vital biological control signals, both chemical and electrical, are the basis for many engineering investigations of the central nervous system, the neuro-endocrine system, the cardiovascular system and the skeletal-motor system. The opportunities open to students who have completed training in Bioengineering are very broad and include extending the body of knowledge useful to the profession of Medicine, contributing at the frontiers of man-in-space research, specifying roles of men in man-machine systems, and promoting the understanding of man's interaction with his normal environment.

In addition to qualified Bachelor of Science in Engineering graduates, candidates for admission may include qualified and interested Bachelor of Science or Bachelor of Arts graduates and individuals who have completed the M.D. degree. Each student's request for admission is reviewed carefully to assess his past academic preparation as it may contribute to his success in the Bioengineering Program.

As a prerequisite the student is expected to have completed organic chemistry and approximately 14 credits of course work in biology from such areas as bacteriology, botany, physiology, psychology, zoology or comparable subjects. A student deficient in biology but otherwise well prepared may make up this deficiency during his first year of graduate work.

The M.S. degree requirement consists of thirty credit hours of graduate level course work beyond the prerequisite requirements; seven are in the biological sciences and twenty-three in mathematics and engineering. Included in these thirty hours is a core curriculum required of all students. The student is also expected to participate in directed research on a continuing basis in an on-going laboratory of his choice.

M.S.E. in Chemical Engineering

Adviser: Professor R. L. Curl, 3026 East Engineering

The minimum requirement for the M.S.E. degree is 30 credit hours with an average grade of B. A master's thesis is not required, but up to 6 credit hours of research are accepted. The course work must include at least 15 hours in chemical engineering (courses with a Chem. Eng. prefix) and at least two courses outside the chemical engineering program. The required courses are Chem. Eng. 595 (research survey), Chem. Eng. 528 (chemical reactor engineering), Chem. Eng. 547 (separations processes), and Chem. Eng. 587 (design). Each student is encouraged to develop a program to fit his professional objectives and should consult with the graduate adviser concerning his plan of study.

A full range of courses is available in several special fields, particularly: biochemical engineering, polymers, environmental engineering, petroleum processes, process control and optimization, and process design. A booklet describing the facilities, faculty, and program is available from the adviser.

M.S.E. in Civil Engineering

Advisory Committee: Professors Wylie (Chairman), Brater, Canale, Cleveland, Rumman.

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 and hydrological, municipal, railway, sanitary, structural, soil, and transportation engineering.

M.S.E. and M.S. in Computer, Information and Control Engineering

Adviser: Professor Irani

This interdepartmental program deals with the theoretical description and practical utilization of information-processing systems: computers, communications systems and control systems. In each area the material is organized according to systems engineering concepts. It is the intent to emphasize those ideas and viewpoints which are most likely to remain useful and relevant as technology changes. In the computer area, digital, analog and hybrid computation and computer systems are studied. Topics in digital computation include programming, logic and system design, computer arithmetic, switching and automata theory, computer graphics. In the communication area topics include information theory and coding, modulation and detection, and parameter estimation. In the control area, which covers both continuous-data and sampled-data systems, topics include theory of dynamical systems, feedback control, optimal control theory, stability theory, and large-scale systems. Considerable work in probability, statistics and stochastic processes is offered to serve all these areas. Although system theoretic concepts form the underlying organization and emphasis, these concepts and principles are continuously related to existing and future technology.

The flexibility and generality in the instructional material make it appropriate for students with a wide range of interests and backgrounds in any of these areas. Students may enter the program from engineering, the physical sciences, or mathematics. This program should appeal to those students holding a B.S.E. in Aerospace, Electrical or Science Engineering who are interested in these topics.

Undergraduate students may start studies in these areas by electing one or more of the following courses: C.I.C.E. 412 (Elec. Eng. 412), C.I.C.E. 450 (Elec. Eng. 450), C.I.C.E. 451 (Elec. Eng. 451), C.I.C.E. 467 (Elec. Eng. 467), C.I.C.E. 482 (Elec. Eng. 482), C.I.C.E. 500, and Math. 448.

Candidates for the degrees Master of Science in Engineering in computer, information and control engineering and Master of Science in computer, information and control engineering must meet the general requirements and be acceptable to the program committee. The student must successfully complete courses totaling 30 credit hours, with at least 14 credit hours in Computer, Information and Control Engineering courses. These must be chosen with the approval of the program adviser so as to include a related set of courses that provides an in-depth study of one subject area. Up to 6 credit hours of humanities courses may be approved.

Computer and Communication Sciences

For study opportunities in the Computer and Communication Sciences offered by the College of Literature, Science, and the Arts, refer to announcements of that college, and of Horace H. Rackham School of Graduate Studies.

M.S.E. in Construction Engineering

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

Advisers: Professors Grimes, Kazda, Lyon, Macnee, and Sharpe.

A candidate 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, which must include at least six credit hours in advanced mathematics, and at least fifteen credit hours in electrical engineering or an associated program: aeronomy; bioengineering; computer, information, and control engineering. At least fifteen hours must be at the 500 level or higher in mathematics, engineering, or a physical or life science. 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-systems engineering, electro-magnetic field theory and optics, control systems, energy conversion devices, microwave engineering, quantum electronics, solid-state devices, and integrated circuits.

M.S. in Electrical Science

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 this 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, Elect. Eng. 520 or their equivalents, and a minimum of six hours of mathematics appropriate to the indivdual'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; bioelectrical sciences. 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.E. in Engineering Materials

Adviser: Professor W. F. Hosford, 4213 East Engineering

A minimum of 30 credit hours of graduate level work must be passed. Of the 30 hours at least 15 hours must be formal class work in materials or metallurgy and must include Mat.-Met. Eng. 590 (1), Mat.-Met. Eng. 520 (3), and graduate level courses in the properties or utilization of a) metals, b) polymers, and c) ceramics. Individual research is not required, but up to six hours of Mat.-Met. Eng. 690 may be used as part of the 30 hour requirement and each student is required to pass either the design course Mat.-Met. Eng. 580 (4) or 4 hours of Mat.-Met. Eng. 690. At least 6 hours must be in courses outside of the metallurgy or materials area.

Each student is encouraged to design his program to satisfy his special interest. A booklet describing the graduate program in more detail is available from the secretary in the graduate committee office, room 4213 East Engineering.

M.S.E. in Engineering Mechanics

Graduate Committee: Professors Wineman, Chairman, Smith, Taylor, Yang, and Yih

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, fifteen from the graduate credit mechanics courses offered in the Department of Engineering Mechanics and at least six hours from graduate credit courses in advanced mathematics. The remaining can be selected from mechanics, mathematics and 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 fifteen required hours if permitted to do so by the adviser. 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 advisers.

M.S.E. in Geodetic Engineering

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 term 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

Adviser: Professor J. A. Gage

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. 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. Candidates may be required to make up deficiencies in their preparation in statistics, linear programming, or computer programming without graduate credit. The program requirements are the same as those for the M.S.E. degree.

M.S.E. in Mechanical Engineering

Adviser: Professor R. Sonntag, 317 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

Adviser: Professor W. F. Hosford, 4213 East Engineering

A minimum of 30 credit hours of graduate level course work must be passed. Of the 30 hours, at least 15 hours must be formal class work in metallurgy and materials, and must include Mat.-Met. Eng. 590 (1), Mat.-Met. Eng. 520 (3), Mat.-Met. Eng. 532 (3). Individual research is not required, but up to six hours of Mat.-Met. Eng. 690 may be used as part of the 30 hour requirement and each student is required to pass either the design course Mat.-Met. Eng. 580 (4) or 4 hours of Mat.-Met. Eng. 690. At least 6 hours must be in courses outside of the metallurgy or materials area.

Each student is encouraged to design his program to satisfy his special interests. A booklet describing the graduate program in more detail is available from the secretary in the graduate committee office, room 4213 East Engineering.

M.S. in Meteorology and/or Oceanography

Adviser: Professor Wiin-Nielsen

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 240, and 241. 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. and M.S.E. in Naval Architecture and Marine Engineering

Adviser: Professor Ogilvie

The applicant should have a bachelor's degree (or equivalent education) in engineering, physics, or mathematics. His preparation should include introductory courses in differential equations, solid mechanics, fluid mechanics, and dynamics. Some experience with a large digital computer is desirable.

The thirty credit hours required for the degree will normally include at least fifteen hours of courses in naval architecture and marine engineering beyond those required for the bachelor's degree, as well as five or more hours of graduate-level mathematics courses.

There are no specific courses required of all students at this level. Most students will specialize in one or more of the following areas, including in their programs the basic courses indicated:

Ship Hydrodynamics: Eng. Mech. 422, Nav. Arch. 525 and 526.

Ship Structures: Eng. Mech. 412, Nav. Arch. 510, 610.

Marine Engineering: Mech. Eng. 535, Nav. Arch. 430, 431, and 535.

Ocean Engineering: M & O 442, Nav. Arch. 450, 525, 526, and 510.

Marine Systems, Operations, and Design: Ind. Eng. 472, Nav. Arch. 572, and at least one chosen from Nav. Arch. 573, 574, 535.

The programs leading to the M.S.E. degree are intended to train students for careers in design, shipyard practice, and management. Applicants for these programs should have obtained the B.S.E. degree in naval architecture and marine engineering, or they should have some experience in the marine field in addition to a bachelor's degree in some other field of engineering. The M.S.E. degree is logically followed by one of the professional degrees. Students anticipating careers in research, development, and teaching will normally work for the M.S. degree, which may then be followed by the Ph.D. degree.

The graduate adviser may allow certain courses in other departments to be used in partial fulfillment of the requirement of fifteen hours in naval architecture and marine engineering, depending upon the background and goals of the individual student. The program in *Marine Systems, Operations, and Design* is normally open only to applicants with a bachelor's degree or equivalent experience in the marine field.

It is possible to obtain the M.S.E. degree in the combined fields of naval architecture and marine engineering and another engineering field. The student should first be admitted to the regular M.S.E. program; he must then present an acceptable study program to the two departments involved; a minimum of thirty-six hours of graduate-level courses is required. This program is particularly recommended to the student for whom the master's degree is likely to be the terminal degree.

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

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.

Students planning to enter the M.S. degree program who do not have an undergraduate degree in Nuclear Engineering should take courses in atomic and nuclear physics (Nuc. Eng. 411 or equivalent) and in advanced mathematics for engineers (Math. 450 or equivalent). Students without these prerequisites will be requested to make up the deficiencies in addition to the 30 hours required for the M.S. degree. A senior level course in heat transfer (Mech. Eng. 471 or equivalent), electronics (Physics 455, Elec. Eng. 337, or equivalent), a course in electromagnetic fields (Elec. Eng. 420, Phys. 405, or equivalent) and a course in digital computer programming (Math. 273 or equivalent) are recommended as desirable preparation.

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

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

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, M.S. in Water Resources Sciences, and M.S. in Water Resources Management

Adviser: Professor Weber

Interdisciplinary programs of advanced study in water resources in the College of Engineering are centered in the Department of Civil Engineering. These include degree programs in Water Resources Engineering, Water Resources Sciences, and Water Resources Management.

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. Program emphasis is placed on development of both technological and socio-economic concepts required for solution of a variety of environmental and water resources problems. Candidates for the degree M.S.E. must complete a minimum of thirty hours of graduate work, planned in consultation with the program adviser, constituting an integrated program. A typical program normally includes courses in: hydrology and water quantity management; water quality and water pollution control; water and wastewater treatment, water chemistry and limnology; air pollution and solid wastes control; systems analysis, operations research techniques, and computer applications; political and institutional factors in environmental and water resource systems.

The degree M.S. in Water Resources Sciences, 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. Each candidate for the degree M.S. in Water Resources Sciences will plan his program in consultation with the program adviser. 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 a research problem.

The objective of the program in Water Resources Management is to provide a working knowledge of the problems and approaches to managing the use and development of water resources and to provide specialization in one of several major aspects of water management approved by the Water Resources Committee. The curriculum is designed to integrate technical, economic, social, and institutional aspects involved in various types of public water management enterprises. A minimum of 48 hours of graduate credit is required to qualify for the degree of Master of Science in Water Resources Management. Of the total credit hours required, approximately 30 should be in courses which emphasize both the physical attributes of water and the policy issues associated with water resources management. Each student must choose 15 elective credits which will reinforce his individual area of specialization. Normally, six credit hours in the field of specialization will be earned in research or in supervised field experience.

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.

Computer, Information and Control Engineer—C.I.C.E.

Civil Engineer—C.E.

Electrical Engineer—E.E.

Industrial Engineer—Ind.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.

Requirements regarding foreign language and nontechnical courses are left to the individual departments or programs and to the Graduate School. A prospective doctoral student should consult the program adviser regarding specific details.

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, and by certain closely associated departments of other units of the University, are listed with a brief description of each. Time Schedules are issued giving hours and room assignments for the courses and sections offered each term.

Designations. The Roman numeral in boldface type, following the course number and title, indicates the position of the course in a sequence of courses on the same subject. Prerequisites appear in italics. When they appear, Roman numerals in light-face type indicate the time at which the department concerned plans to offer the course: I, fall; II, winter; III, spring-summer; IIIa, spring half; IIIb, summer half. (See under Term for definitions relating to the several terms). The italic number in parentheses indicates the hours of credit for the course, for example, (*3*) denotes three credit hours, or, (*to be arranged*) denotes credit to be arranged.

Prerequisites For Engineering Courses

In general, the prerequisites listed for a course designates specific subject materials and/or skills expected to have been mastered before electing the course (or, in some cases concurrent with).

Course Equivalence. Unless otherwise stated, the phrase "or equivalent" may be considered an implicit part of the prerequisite for any course. When a student has satisfactorily completed a course that is not listed but is believed to be substantially equivalent to one specified as a prerequisite for a course he wants to elect, he may consult his program adviser and upon concluding that equivalency is satisfied, election may be approved.

Permission of Instructor. The phrase "or permission of instructor (or department)" may be considered an implicit part of the statement of prerequisites for any course. When permission is a stated requirement, or when a student does not have the stated prerequisite for a course but can give evidence of background, training, maturity, or high academic record, he should present to his program adviser a note of approval from the instructor or department concerned.

What the Course Number Indicates. The numbering of each course is designed to indicate the general level of maturity and prior training expected.

100: Freshman level courses
200: Sophomore level courses
300: Junior level courses
*400: Senior level courses
500: Predominantly Graduate level courses
600 and above: Graduate level courses

Unless a phrase such as "Junior Standing", "Senior Standing" or "Graduate Standing" is part of the list of prerequisites for a course, a student may elect

* A 400 level course listed in the *Announcement* of the Horace H. Rackham School of Graduate Studies may be elected for graduate credit when approved by the student's graduate program adviser.

an advanced level course relative to his current status if the other prerequisites are satisfied. If the difference in standing level is greater than one academic year, it is usually not wise to elect an advanced level course without first consulting the department or the instructor offering the course.

Aerospace Engineering

Department Office: 1077 East Engineering
See Page 112 for statement on Course Equivalence.

200. General Aeronautics and Astronautics. *Prerequisite: Physics 140,* 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.

201. Conquest of Air and Space. II. *(2).*
An introduction to the physical principles of flight within the atmosphere and in space, to the major historical developments in the conquest of air and space, and to the current state of aerospace developments and their role in national and world affairs. Not open to students enrolled in the College of Engineering.

314(Eng. Mech. 314). Structural Mechanics I. *Prerequisite: Eng. Mech. 211.* 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. 340 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.

390. Undergraduate Seminar. *Prerequisite: Junior standing.* I and II. *(1).*
A series of seminars by noted outside speakers designed to acquaint undergraduates with both current problems and state of the art of the aerospace industry. Will involve a short term project or paper pertinent to one of the seminar topics.

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

415. Principles of Structural Mechanics. *Prerequisite: Eng. Mech. 211 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. (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.* 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. (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. (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 propellor 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). Introduction to Aeronomy. *Prerequisite: senior or graduate standing in a physical science or engineering.* I. *(3).*
An introduction to physical processes in the upper atmosphere; density, temperature, composition, and winds; atmospheric radiation transfer processes and heat balance; the ionosphere; rocket and satellite measurement techniques.

465. Aeronomical Measurements. *Prerequisite: Aero. Eng. 464 or Elec. Eng. 495.* II. *(3).*
Theory and effectiveness of techniques for making upper atmosphere and space measurements as well as measurements of the lower atmosphere from space. Photometry, spectrometry, interferometry and radiometry; gas dynamic methods, mass spectrometry and ionospheric probing.

466. Aeronomical Measurements Laboratory. *Prerequisite: preceded or accompanied by Aero. Eng. 465.* II. *(2).*
Measurement projects in gas dynamics and in radiation phenomena in all parts of the electromagnetic spectrum of significance to atmospheric and space research. Emphasis is placed on ground based techniques which yield useful aeronomical data.

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.

482. Sounding Rocket and Payload Design. *Prerequisite: Aero. Eng. 314 and 441.* I and II. *(4).*
Design of the instrumentation, payload and propulsion units of a sounding rocket for making atmospheric measurements up to satellite altitudes. Measuring techniques, instruments, housekeeping, telemetering, environmental tests, propulsion, staging, stability, heating, trajectories and dispersion. 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.

485. Aerospace Communication Systems. *Prerequisite: Math. 450, Elec. Eng. 314. (3).*
Introduction to the design of space communications and tracking systems for the aerospace system designer. Basic principles in the design of space communications and tracking systems, including modulation-demodulation techniques, frequency and time division multiplexing, methods of data storage, system gain considerations, power sources, antennas, propagation and tracking methods. Application to system problems emphasized.

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.

514(Eng. Mech 511). Foundations of Structural Mechanics I. *Prerequisite: Aero. Eng. 414. (3).*
Elements of the analysis of structures. Includes plates of various shapes, loading, and boundary conditions, effects of in-plane loading; shells of revolution, cylindrical shells, bending and membrane theories; plastic analysis of structures beams, frames, plates; plastic collapse mechanism. Applications of aerospace interest.

515(Eng. Mech. 512). Foundations of Structural Mechanics II. *Prerequisite: Aero. Eng. 514. (3).*
Behavior of structures in a thermal environment, heat conduction, aerodynamic heating of high speed vehicles, thermal stresses and deflections, thermal instabilities, discussion of material properties at elevated temperatures. Elements of the theory of linear viscoelasticity.

520. Gasdynamics I. *Prerequisite: Aero. Eng. 420 or 425. (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. (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. (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. (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. (3).*
A study of some modern topics of flow problems not covered in the traditional gasdynamics of idea 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. (3).*
Analysis and performance of liquid and solid propellant rocket powerplants; propellant thermochemistry, heat, transfer, system considerations, advanced rocket propulsion techniques.

540. Space Dynamics I. *Prerequisite: Eng. Mech. 340. (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.

542. Astrodynamics I. *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 suborbtial, 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 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.

549(Eng. Mech. 549) (Mech. Eng. 549). Random Vibrations of Mechanical Systems. *Prerequisite: Eng. Mech. 340 or Eng. Mech. 343.* II. *(3).*
Random mechanical inputs: wind buffeting; earthquakes; surface irregularities. Engineering applications include response of a linear spring-mass system and an elastic beam to single and multiple random loading. Failure theories. Necessary concepts such as ensemble averages, correlation functions, stationary and ergodic random processes, power spectra, are developed heuristically.

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

596. Aurora and Airglow. *Prerequisite: permission of instructor.* II. *(3).*
Morphology and physics of the aurora and airglow. Emission spectra in the aurora and their atomic and molecular origin; proton aurora; metastable excitation; calculation of emission profiles. Night- and day-glow; pre-dawn and post-twilight enhancements; mid-latitude red arc; excitation mechanisms.

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. (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. (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. (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. (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. (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.

640. Space Dynamics II. *Prerequisite: Aero. Eng. 540.* II. *(2).*
Hamilton's equations, canonical transformations, and Hamilton-Jacobi theory. Applications to orbital problems. General perturbation theory. Introduction to special relativity.

642. Astrodynamics II. *Prerequisite: Aero. Eng. 542.* II. *(3).*
Orbit determination. Systems of canonical equations. Perturbation theory with applications to the motion of an artificial satellite. Lunar and planetary theories.

650. Computational Methods for Flight Simulation. *Prerequisite: Aero. Eng. 540, and C.I.C.E. 482 or Elect. Eng. 365. (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. 640. (2).*
Error analysis of numerical integration methods. Comparison of Cowell's method, Enke's method and variation-of-parameters in terms of accuracy and convenience. FORTRAN programming of integration methods. Student programming and solution of trajectory problems.

670. Guidance and Navigation of Aerospace Vehicles. *Prerequisite: a course in feedback control.* II. (3).
Principles of space vehicle, homing and ballistic missile guidance systems in two and three dimensions. Explicit, linear perturbation, and velocity-to-be gained guidance modes. Mechanization by inertial and other means, including strapped-down and stable-platform inertial systems. Celestial navigation procedures with deterministic and redundant measurements. Application of Kalman filtering to recursive navigation theory.

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: C.I.C.E. 550. (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.

675. Optimization of Space Trajectories. *Prerequisite: permission of instructor.* II. *(3).*
Necessary and sufficient conditions for ordinary extremum and variational problems, with emphasis on the problem of Bolza. Applications of the calculus of variations to optimal space trajectories. Problems with control and state variable inequality constraints. Iterative computational methods for two-point boundary-value problems, including the gradient method, Newton's method, and quasilinearization.

676. Optimal Guidance. *Prerequisite: Aero. Eng. 675 or C.I.C.E. 540. (3).*
Optimum guidance modes, including the path-adaptive mode, iterative guidance mode, and neighboring optimum guidance. The effect of normality and conjugate points in guidance analysis. Applications to space missions involving high thrust, low thrust, impulsive thrust and re-entry. Necessary conditions for singular guidance problems. Future needs in guidance theory.

721. Turbulence. *Prerequisite: Aero. Eng. 620. (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 magnetohydrodynamic 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. (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.

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(Elec. Eng. 895). Seminar in Space Research. *Prerequisite: permission of instructor. (To be arranged).*
Detailed analyses of objectives, procedures, and results of research being carried out at The University of Michigan. Topics will include the following: structure of the upper atmosphere; measurement of temperature, pressure, density, composition, and winds. The ionosphere; measurement of ion and electron density and temperature. Investigation of radio waves incident on the earth at frequencies absorbed by the ionosphere by means of instrumented satellites. Interpretation of infrared data from meteorological satellites. Research in attitude control of multistage sounding rockets.

900. Research. *(To be arranged).*
Specialized individual or group problems of research or design nature supervised by a member of the staff.

Bioengineering

Office: 207 West Engineering
See Page 112 for statement on Course Equivalence.

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

471(Elec. Eng. 471). Electrical Biophysics. *Prerequisite: Elec. Eng. 311 or 314 or 215. (3).*
Electrical biophysics of muscle, nerve and synapse. Hodgkin-Huxley equation, electrical conduction in excitable tissue, phase plane analysis and modeling of neural elements, semiconductor characteristics of biological membranes, biopotential mapping and biological noise.

516(Chem. Eng. 516). Dynamics of Biochemical Systems. *Prerequisite: a course in physical chemistry, a course in biology. (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.

525(Psych. 525) (Com. Comm. Sci. 550). Information Processing in Behavioral Systems. *Prerequisite: enrollment in Bioengineering Program or permission of instructor.* I. *(3).*
Surveys four areas of experimental and mathematical psychology, such as sensory, learning, skilled performance and thinking and reasoning with emphasis on the relations between empirical data and logical, mathematical, or computer simulation models of underlying processes.

534(Ind. Eng. 534). Biomechanics and Physiology of Work. *Prerequisite: Ind. Eng. 333.* II. *(3).*
Limitations of the human body in coping with stressful situations. Concepts to be included are: skeletal muscle physiology and mechanics, skeletal articulation and mechanics, circulatory and pulmonary system function and limitations, and nervous system control and limitations.

546(Mech. Eng. 546). Biomechanics I. *Prerequisite: Mech. Eng. 340 or Mech. Eng. 540.* I. *(3).*
Statics, kinematics, and dynamics of body motions; study of body motion response to various dynamic load inputs utilizing lumped parameter methods; properties of biological materials; tolerance of man to adverse environments including impact, vibration, weightlessness; appropriate physiological failure criteria.

571(Elec. Eng. 571). Introduction to Neurophysiological Systems. *Prerequisite: Elec. Eng. 350 or C.I.C.E. 450.* I, II and III*a*. *(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(Elec. Eng. 573) (Zool. 573). Bioelectrical Measurement. *Prerequisite: mathematics, physics, and chemistry; graduate standing; and permission of instructor.* I and I. *(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.

590. Directed Research. *(To be arranged).*
Provides opportunity for Bioengineering students to participate in the work of laboratories devoted to living systems studies.

690(Physiol. 690) (Zool. 690) (Anatomy 690) (Psych. 690) (Pharmacol. 690). Neuroscience. *Prerequisite: graduate standing or equivalent. (3).*
Study of nervous systems including comparative aspects, structure, function, chemistry, behavior, and pathology.

691(Elec. Eng. 691) (Physiol. 691) (Zool. 691). Neurosciences Laboratory. *Prerequisite: preceded or accompanied by Physiol. 690 and permission of instructor. (2).*
Interdepartmental staff. Laboratory exercises and demonstrations in neurobiology.

819(Physiol. 819). Bioengineering Physiology. *Prerequisite: Zool. 106 or equivalent, and permission of instructor. (4).*
Quantitative description of the structure and function of mammalian systems, including the neuromuscular, cardiovascular, respiratory, renal and endocrine systems. Mathematical models are used to describe system performance where applicable. Lectures, laboratories, and problem sessions.

820(Physiol. 820). Bioengineering Physiology Seminar. *Prerequisite: Physiol. 819 or equivalent and differential equations, and permission of instructor.* III*a. (2).*
Applications of mathematical modeling and control theory to the analysis of the cardiovascular, respiratory, renal, endocrine, and temperature regulating systems. Lectures and student seminar presentations.

890. Bioengineering Seminar. *(To be arranged).*

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

Business Administration—School of Business Administration

Office: 164 Business Administration

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

Engineering undergraduate students interested in pursuing the Master of Business Administration degree following the completion of their Bachelor's degree in Engineering, are encouraged to consult with counselors in the Office of Admissions and Student Services, 164 Business Administration. The careful selection of undergraduate courses in Mathematics, English, and Economics is crucial for admission to the M.B.A. program at Michigan.

The business courses below are of special interest to students enrolled in the undergraduate engineering curriculum. 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 descriptions of the following courses in Business Administration, see the *Announcement* of the School of Business Administration:

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

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

Finance
F 300. Money and Banking. *(3).*
F 301. Business Finance. *(3).*

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

Marketing
M 300. Marketing Management I. *(3).*
M 301. Marketing Management II. *(3).*

Organization Behavior and Industrial Relations
*OB 300. Behavioral Theory in Management. *(3).*
*OB 315. Management of Personnel. *(3).*
OB 322. Management of Union Relations. *(3).*

Planning and Control
PC 311. Production Management. *(3).*

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

Chemical Engineering

Department Office: 2028 East Engineering
See Page 112 for statement on Course Equivalence.

230(Mat.-Met. Eng. 230). Thermodynamics I. *Prerequisite: Chem. 103 or 104; must be accompanied by Chem. Eng. 231(Mat.-Met. Eng. 231). (3).*
An introduction to applications of the first and second laws of thermodynamics. Material and energy balances, the equilibrium concept. Properties of fluids and solids. Engineering systems.

231(Mat.-Met. Eng. 231). Chemical Engineering Laboratory. *Prerequisite: must accompany Chem. Eng. 230(Mat.-Met. Eng. 230). (1).*
Quantitative experiments involving the first law of thermodynamics and thermodynamics properties.

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

330. Thermodynamics II. *Prerequisite: Chem. Eng. 230(Mat.-Met. Eng. 230) and Chem. 468. (3).*
Development of fundamental thermodynamic property relations 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.

341. Rate Processes I. *Prerequisite: Chem. Eng. 230(Mat.-Met. Eng. 230). (3).*
A study of fluid mechanics and heat transfer. Equations of continuity, energy, and momentum. Viscosity, dimensional analysis, and flow through equipment. Heat transfer by conduction, convection, and radiation.

342. Rate Processes II. *Prerequisite: Chem. Eng. 341; must be accompanied by Chem. Eng. 344. (3).*
Diffusion and mass transfer in gases and liquids in laminar and turbulent flow. Dimensional analysis and correlation of data. Fundamentals of kinetics, catalysis, and reactor design. Analysis of rate data and use of rate data in design.

343. Separation Processes. *Prerequisite: Chem. Eng. 342. (3).*
Introduction and survey of separations based on mechanical properties, phase equilibria, and rate processes. Emphasis on analysis and modeling of separation processes. Staged and countercurrent operations.

344. Rate Processes Laboratory. *Prerequisite: must accompany Chem. Eng. 342. (1).*
Quantitative experiments in fluid flow, heat and mass transfer, and kinetics.

407. Chemical Engineering Calculations I. *Prerequisite: Math. 316 or 404 and Chem. Eng. 342. (3).*
Applications of topics in mathematics to engineering problems. Solutions to ordinary and partial differential equations, orthogonality properties, matrix notations, numerical analysis.

417. 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.

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

444(Mat.-Met. Eng. 444). Properties of Gases, Liquids, Solids, and Surfaces. *Prerequisite: Chem. 469 and Chem. Eng. 330. (3).*
A study of chemical and phase equilibria involving the various states of matter. Applications of phase rule to multicomponent and mixed-state systems. Kinetics of state and phase changes. Structure and properties of gases, liquids, solids, and surfaces. Prediction and correlation of physical, chemical, and transport properties of various states and aggregates.

451(Mat.-Met. Eng. 451). Introduction to High Polymers. *Prerequisite: junior standing in engineering or science. (4).*
Preparation, properties, and utilization of polymeric materials. Lectures, recitation, and laboratory.

460. Engineering Operations Laboratory. *Prerequisite: Chem. Eng. 343. (3).*
Experimentation in rate and separation processes. Introduction to the use of instrumental analysis and process control. Laboratory conferences and reports.

486(Mat.-Met. Eng. 486). Engineering Materials in Design. *Prerequisite: senior standing. (3).*
The study of the selection and specification of engineering materials for use in the chemical industry. Metals, ceramics, polymers, non-metals, coatings.

487. Principles of Chemical Engineering Design. *Prerequisite: Chem. Eng. 343 and senior standing. (3).*
Introduction to the principles of equipment and process design of reactors and other chemical process units. Cost of equipment, raw materials, and service auxiliaries. Three lecture hours per week plus one afternoon calculational and tutorial workshop.

488. Practice of Chemical Engineering Design. *Prerequisite: Chem. Eng. 444 (Mat-Met. Eng. 444) and Chem. Eng. 487 and preceded or accompanied by Chem. Eng. 486(Mat-Met. Eng. 486). (3).*
Practice of process design; dynamics and control of processes, economics of processes, principles of capital budgeting and cost effectiveness. Three lecture hours per week plus one afternoon calculational and tutorial workshop.

490(Mat.-Met. Eng. 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.

507. Chemical Engineering Calculations II. *Prerequisite: Chem. Eng. 407. (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.

508. Numerical Methods in Chemical Engineering. *Prerequisite: Engr. 102. (3).*
Numerical approximation: interpolating, least squares, and Chebyshev polynomials; spline functions. Numerical integration and differentiation. Single and simultaneous linear and nonlinear equations. Ordinary and partial differential equations. Implementation of numerical methods on the digital computer. Applications to problems in fluid mechanics, heat transfer, reaction engineering, and related areas.

509. Engineering Experiments and Their Design. *(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.

511(Mat.-Met. Eng. 511). Polymerization Reactions. *Prerequisite: A course in physical chemistry and a course in organic chemistry. (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.

516(Bioeng. 516). Dynamics of Biochemical Systems. *Prerequisite: a course in physical chemistry, and a course in biology. (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.

526. Heat Transfer I. *Prerequisite: Chem. Eng. 341. (2).*
Conduction, convection, and radiation; applications to processes in the chemical and petroleum industries.

527. Fluid Flow I. *Prerequisite: Chem. Eng. 341. (2).*
Applications of basic fluid dynamics to chemical engineering systems. Laminar and turbulent flow of Newtonian and non-Newtonian fluids in conduits and films. Introduction to the dynamics of suspended particles and drops, boundary layers, and interfacial transport phenomena.

528. Chemical Reactor Engineering. *Prerequisite: Chem. Eng. 342. (2).*
Analysis of kinetic, thermal, diffusive, and flow factors on reactor performance. Topics include batch, plug flow, backmix reactors, empirical rate expressions, residence time analysis, catalytic reactions, stability, and optimization.

529. Mass Transfer. *Prerequisite: Chem. Eng. 342. (2).*
Formulation of diffusional mass balances; diffusion in solids, liquids and gases; Fick's first and second laws; convective mass transfer, modeling of mass transfer systems.

537. Thermodynamic Relations and Applications. *Prerequisite: Chem. Eng. 330. (3).*
The fundamental property relation and its application to physical and chemical equilibria in homogeneous and heterogeneous systems. Magnetic, electric, surface, and stress effects. Fugacities and activities of the constituents of multicomponent mixtures are determined through analyses of experimental PVT, concentration, and electrochemical potential data.

546. Chemical Engineering of Water. *Prerequisite: Chem. 225 and Chem. Eng. 343. (3).*
Development and modification of chemical and metallurgical process and plant designs as dictated by raw water and effluent disposal requirements.

547. Separations Processes II. *Prerequisite: Chem. Eng. 343. (3).*
Analysis and design of multicomponent separations systems including adsorption, distillation, extraction, and ion exchange. Emphasis on the concepts of the equilibrium stage and differential contactor.

549.(Mech. Eng. 538). Air Pollution Control. *Prerequisite: Chem. Eng. 341, or 342, or Mech. Eng. 471.* II. *(3).*
Principles of control techniques, fundamentals or process modification to reduce pollution, and legal requirements. Includes furnace and internal combustion sources, particulate control devices, and vapor control systems.

566. Process Control in the Chemical Industries. *Prerequisite: Chem. Eng. 343 and 460. (3).*
Techniques of regulation applied to equipment and processes in the chemical and petrochemical industries. Controller types and their operation, transducers, and final control elements. Direct digital control. Pressure, liquid level, temperature and composition control; alarms, interlocks and backup systems.

573(Mat.-Met. Eng. 573). Corrosion of Metals and Alloys. *Prerequisite: Mat.-Met. Eng. 371 or Chem. Eng. 486. (3).*
Fundamentals involved in choosing a metal for use in a corroding medium.

585. Production and Processing of Petrochemicals. *Prerequisite: Chem. Eng. 343. (3).*
Production, pipelining, conservation, processing and storage of crude oil and natural gas. Chemical engineering calculations, economics, and design applied to reservoir engineering, petroleum processing, refining and other related areas of the petrochemicals industry.

587. Chemical Process Design. *(2 or 4).*
First half-term: Selection and design of chemical, biochemical, or petrochemical processes, equipment and control systems; economic studies; comparison and optimization. Equipment evaluation and estimating procedures; computer methods. Second half-term: Engineering design and economic analysis of a process. Original and individual work, and excellence of reporting are emphasized. Oral examination on final written report.

588. Optimization and Control of Chemical Systems. *Prerequisite: Chem. Eng. 407 or 507 or 508. (3).*
Techniques for finding extrema of functions and functionals relating to chemical process problems. Solution methods, including digital computation, alternative and approximate procedures. Geometrical, dynamic and linear programming. Constrained variables and systems. Variational methods, the maximum principle, search methods. Sensitivity and errors.

595. Chemical Engineering Research Survey. *(1).*
Research activities and opportunities in Chemical Engineering program. Lectures by University of Michigan faculty and guest lecturers. Topics are drawn from current research interests of the faculty. Brief weekly reports.

607. Chemical Engineering Calculations III. *Prerequisite: Chem. Eng. 507. (3).*
Topics selected from variational techniques and optimization of chemical processes. Linear and nonlinear stability analyses of chemical processes. Perturbation methods in physico-chemical systems. Kinetics of coupled rate processes.

625. Coupled Rate Processes. *Prerequisite: Chem. Eng. 528, and 526 or 527 or 529. (3).*
Theoretical and experimental phenomena associated with the coupling of two or more rate processes. Material selected from contemporary chemical engineering, involving reaction kinetics in two-phase flow, thermal effects in chemical reactors, coupled diffusional processes, coupled chemical reactions.

626. Heat Transfer II. *Prerequisite: Chem. Eng. 526. (2).*
Topics to be selected primarily from: boiling, condensation or multicomponent vapors, extended surface heat transfer, radiant and convective transfer involving gases and flames, natural convection, and heat transfer with chemical reaction.

627. Fluid Flow II. *Prerequisite: Chem. Eng. 527. (3).*
Special topics in fluid mechanics and multiphase flow applied to chemical engineering. Theoretical, empirical, and engineering concepts ranging from research to design and performance in multiphase flow, non-Newtonian flow, the mechanics of bubbles, and interfaces. Stability of jets and liquid films. Cavitation and fluidization.

628. Chemical Kinetics and Reactors. *Prerequisite: Chem. Eng. 528. (3).*
Mathematical and experimental characterization of kinetic systems, including topics from homogeneous, heterogeneous, photochemical, and chain reactions.

637. Statistical and Irreversible Thermodynamics. *Prerequisite: Chem. Eng. 537. (3).*
The laws of probability and statistics are applied to microscopic matter to yield properties of macroscopic systems. Relations between classical and statistical thermodynamics are developed. Coupling of irreversible processes is treated through the entropy balance and microscopic reversibility.

648. Electrochemical Engineering. *Prerequisite: Chem. Eng. 528. (2).*
Analysis of electrochemical systems from a theoretical and practical point of view. Topics include the application of electrochemical thermodynamics and kinetics to batteries, fuel cells, electroplating, electrosynthesis, and corrosion.

687. Chemical Process Design II. *Prerequisite: Chem. Eng. 587. (3).*
The application of machine computation to process and equipment design and simulation. Process-oriented languages, data banking, decompositional methods related to process system arrangement. Heuristic synthesis of equipment sequences. Applications in chemical, petrochemical, and petroleum industrial processes. Recycle, chemical reactors, heat transfer, and separations are emphasized.

695. Research Problems in Chemical Engineering. *(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 faculty. Any problem in the field of chemical engineering may be selected. The student writes a final report on his project.

696. Selected Topics in Chemical Engineering. *(To be arranged).*

697. Problems in Chemical Engineering. *(To be arranged).*

698. Directed Study in Chemical Engineering. *(To be arranged).*

895. Seminar in Chemical Engineering. *(To be arranged).*

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

*Chemistry**

Department Office: 2035 Chemistry Building

Professors Overberger and Taylor; Professors Bartell, Blinder, Brockway, Dunn, Elving, Gordus, Lawton, Martin, Nordman, Oncley, Rulfs, Smith, Stiles, Tamres, and Westrum; Associate Professors Brintzinger, Ege, Kopelman, Kuczkowski, Lohr, Longone, J. E. Mark, Morris, Rasmussen, and Wiseman; Assistant Professors Ashe, Curtis, Empedocles, Green, Griffin, Groves, Haschke, Le Quesne, Marino, Rudolph, Sacks, Sharp, and Verdieck; Visiting Assistant Professors Copeland, and Dull.

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

103. General and Inorganic Chemistry. *Prerequisite: three years of high school mathematics.* I, II, and III*a*. *(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. *(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.

* College of Literature, Science, and the Arts.

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

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.

196. General Chemistry (Honors). *Prerequisite: Advanced placement credit in Chemistry or permission of instructor; Math. 115 or equivalent, to be taken concurrently.* I. *(5).*
Laboratory fee. Four lecture-recitation periods and four hours of laboratory work. Equilibria, atomic and molecular structure, introduction to use of thermodynamic functions, kinetics and topics from inorganic chemistry.

225. Organic Chemistry. *Prerequisite: Chem. 105, 106, 191, or 196.* 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, II, and III*a*. *(2).*
Laboratory fee. 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).*
Laboratory fee. Continuation of the study of laboratory techniques involved in organic chemistry.

265. Principles of Physical Chemistry. *Prerequisite: Chem. 106, 191, or 196, and preceded or accompanied by Math. 116 or 186 and Physics 140-141 or 190.* 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.

346. Quantitative Analysis. *Prerequisite: Chem. 105, 106, 191, 196, or 265.* I and II. *(4).*
Laboratory fee. 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, II and III*a*. *(3).*
Laboratory fee. 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. *(2).*
Theory and applicability of the principal physical and physiochemical approaches used in chemical analysis, including electrical, optical, and radiochemical methods. Lecture, recitation.

448. Physical Methods Laboratory. *Prerequisite: to be preceded or accompanied by Chem. 447. I, II. (2).*
Laboratory fee. Laboratory experiments illustrating techniques or analysis discussed in Chem. 447.

468. Physical Chemistry. *Prerequisite: Physics 240-241 or 190-191, 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: Math. 316; Chem. 468 is recommended.* I, II and III*a (3).*
Electrochemistry, atomic concepts of matter and energy, molecular and crystal structures, chemical kinetics.

481. Physicochemical Measurements. *Prerequisite: Chem. 346 or 393 and 468.* I, II, III*a. (2).*
Laboratory fee. Laboratory work, including determinations of molecular weights, measurements of properties of pure compounds and solutions, homogeneous and heterogeneous equilibria, kinetics, electrochemistry, and atomic and molecular properties. One discussion period dealing with treatment of errors and related topics.

482. Physicochemical Measurements. *Prerequisite: Chem. 481.* I, II, and III*a. (2).*
Laboratory fee. A continuation of Chemistry 481 involving experiments at a more advanced level.

538. Organic Chemistry of Macromolecules. *Prerequisite: Chem. 226 or 295.* I. *(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).*
Laboratory fee. Elementary theory of nuclear transitions and of interactions of radiations with matter. Laboratory work deals with methods of production, manipulation, and detection of radioactive materials.

Civil Engineering

Department Office: 304 West Engineering
See Page 112 for statement on Course Equivalence.

262. Geodetic Engineering I. *Prerequisite: Eng. 102 or 110 and Math. 116.* I. *(4).*
Principles of geodetic measurements; use of theodolite, tilting level, and precise taping procedures; reduction of observations for calibration and observational procedures; data reduction by computer; simple positional computations and adjustments; topographic mapping; horizontal and vertical curves, and elementary earthwork computations. Two lectures, two laboratory sessions per week.

263. Geodetic Engineering II. *Prerequisite: Civ. Eng. 262.* II. *(3).*
Principles of geodetic engineering computations; coordinates 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.

264. Basic Surveying. *Prerequisite: Math. 105 or 115.* I. *(2).*
Use of basic surveying instruments; leveling, taping, horizontal angle measurements; traverse surveys; computation, use of calculating machines. For non-civil engineering students or those having permission of program adviser.

312. Theory of Structures. *Prerequisite: preceded or accompanied by Eng. Mech. 211.* I, II and III*a*. *(3).*
Calculations of reactions, shears, and bending moments in simple, restrained, and continuous beams due to fixed and moving loads, simple trusses with fixed and moving loads; determinate frames; columns; tension members; girders; introduction to design.

313. Elementary Design of Structures. *Prerequisite: Civ. Eng. 312.* I and II. *(3).*
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.

324(Eng. Mech. 324). Fluid Mechanics. *Prerequisite: Eng. Mech. 340, preceded or accompanied by Mech. Eng. 335.* I and II. *(3).*
Principles of mechanics applied to real and ideal fluids. Topics include fluid properties and statics; continuity, energy and momentum equations by control volume; dimensional analysis and similitude; laminar and turbulent flow; boundary layer, drag, lift; incompressible flow in pipes; free-surface flow; adiabatic flow of ideal gases in conduits; fluid measurement and turbomachinery.

351. Analysis of Civil Engineering Materials. *Prerequisite: Mat.-Met. Eng. 250 and Eng. Mech. 211.* I and II. *(2).*
Relationships of atomic structure to engineering properties and the evaluation of these properties for a variety of materials important to civil engineering. Comparison of load-time-deformation characteristics of different materials and their response to service environments. Laboratory demonstration and exposure to performance of materials.

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.

405. Civil Engineering Systems. *Prerequisite: Math. 216.* I and II. *(3).*
Introduction to optimization techniques with applications to civil engineering systems. Statistical topics, stochastic processes, mathematical programming, computer applications, economic concepts and decision making.

415. Reinforced Concrete. *Prerequisite: Civ. Eng. 312.* I, II, and III*a*. *(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: Civ. Eng. 324 (Eng. Mech. 324).* 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. 102 or 110, and Civ. Eng. 324 (Eng. Mech. 324).* I and II. *(2).*
Gradually varied flow; system optimization; orifices, weirs and venturi meters; turbomachines; flow in piping systems; unsteady flow. Lecture, laboratory and computation.

430. Special Problems in Construction Engineering. *Prerequisite: permission of instructor.* I, II, III*a*, and III*b*. *(1-3).*
Advanced problems selected from a wide range of construction engineering areas.

431. Construction Contracting. *Prerequisite: Junior standing.* I. *(3).*
Emphasis on business aspects of construction. Includes estimating, cost control, insurance, bonds, organization, business methods, management functions and techniques, labor relations, and safety.

432. Construction Engineering. *Prerequisite: Junior standing.* II. *(3).*
Emphasis on equipment and method aspects of construction. Includes equipment policies and the application of engineering principles to construction methods.

445. Engineering Properties of Soil. *Prerequisite: Civ. Eng. 351.* 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. 262, Eng. Mech. 340, and preceded or accompanied by 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.* 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.

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. *Prerequisite: Eng. Mech. 324.* 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: Civ. Eng. 324(Eng. Mech. 324).* 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. *Prerequisite: Senior or graduate standing.* 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.* 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 III*a*. *(3).*
Principles of virtual displacement and virtual work; energy theorems; deflections by graphical and numerical methods; force and displacement methods.

513. Design of Structures. *Prerequisite: Civ. Eng. 313 and 415.* I and II. *(3).*
Structural design problems and reports; introduction to composite and plastic design; modern trends in bridge and building design.

514. Rigid Frame Structures. *Prerequisite: Civ. Eng. 512.* II and III*b*. *(3).*
Analysis of rigid frames by slope deflections, methods of successive approximations, and stiffness matrix procedures including computer solutions.

515. Prestressed Reinforced Concrete. *Prerequisite: Civ. Eng. 313 and 415.* I and III*a*. *(2).*
Fundamental principles of prestressing; prestress losses due to shrinkage, elastic action, plastic flow, creep, etc.; stress analysis and design of prestressed concrete sructures.

518. Design in Reinforced Concrete. *Prerequisite: Civ. Eng. 415 and preceded or accompanied by Civil Eng. 514.* II. *(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.* 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 aquifers; ground water and well hydraulics.

523. Flow in Open Channels. *Prerequisite: Civ. Eng. 324(Eng. Mech. 324).* 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.

524. Advanced Hydraulics. *Prerequisite: Civ. Eng. 324(Eng. Mech. 324).* 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. 420 and preceded or accompanied by Civ. Eng. 421.* 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.

527. Coastal Hydraulics. *Prerequisite: Civ. Eng. 324 (Eng. Mech. 324).* I. *(3).*
Equations of oscillatory wave motion; generation of waves by wind; refraction; energy transmission, breaking waves, diffraction; energy dissipation; run-up and overlapping; wave forces; the design of seawalls and breakwaters; currents and wind tides; shore erosion processes; harbor design.

529. Hydraulic Transients I. *Prerequisite: Civ. Eng. 421.* 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. *(3).*
Elements of cost in construction; determination of unit cost; analysis of cost records; estimate of cost; amortization and debt retirement; quantity surveys.

532. Construction Methods and Equipment. II. *(3).*
Open to seniors and graduates. Contractors' organizations; plant selection and layout; equipment studies; methods of construction. Seminar. A student may not elect both Civ. Eng. 532 and Civ. Eng. 535 for credit to satisfy a technical option group.

533. Industrialized Construction Systems. I. *(2).*
History and development of building systems; types of systems; scheduling, transportation, erection and marketing of construction systems.

535. Analysis of Highway Construction Operations. *Prerequisite: Civ. Eng. 470 and preceded or accompanied by Civ. Eng. 531.* 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.

541. Soil Sampling and Testing. *Prerequisite: preceded or accompanied by Civ. Eng. 445.* I and III*a*. *(1).*
Field and laboratory practice in sampling and testing soils for engineering purposes. Field sampling with standard split-spoon sampler, Dutch static cone sampler, field vane shear test; laboratory tests including direct shear, unconfined compression, triaxial, consolidation, expansion. Laboratory.

542. Physico-Chemical Principles in Soil Engineering. *Prerequisite: Civ. Eng. 445.* I. *(3).*
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. Lectures and laboratory.

543. Soils in Highway and Airport Engineering. *Prerequisite: Civ. Eng. 445 and 470.* III*a*. *(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. Foundation Engineering. *Prerequisite: Civ. Eng. 445.* I and II. *(3).*
Application of principles of soil mechanics to: determination of bearing capacity and settlement of spread footings, mats, single piles and pile groups; site investigation, evaluation of data from field and laboratory tests; estimation of stresses in soil masses; and lateral resistance of piles and pile groups.

546. Stability of Earth Masses. *Prerequisite: Civ. Eng. 445.* II. *(3).*
Stability of hillsides and open cuts, geologic considerations; stability of man made embankments including earth dams and structural fills, compaction and placement of soil in earth embankments, problems of seepage and rapid drawdown, earthquake effects, slope stabilization techniques; lateral earth pressures and retaining walls, braced excavations.

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. Foundations for Marine Structures. *Prerequisite: Civ. Eng. 445.* I. *(3).*
Effects of seepage and dewatering on design of waterfront structures. Soil retaining structures, cellular cofferdams, anchored bulkheads. Compaction and consolidation of soil masses. Water wave forces on offshore and harbor structures. Soil-structure interaction for offshore towers, piers, wharves, sea walls, and jetties.

549. Case Studies in Soil Mechanics Practice. *Prerequisite: Civ. Eng. 545 or 546.* 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. Lectures and seminar.

550. Construction Materials Requirements and Control. *Prerequisite: Civ. Eng. 351.* I. *(3).*
Development of specifications for construction materials; desired properties and economic considerations. Non-destructive and destructive methods for measuring and evaluating materials in the laboratory and in the field. Plant, site and performance evaluation. Sampling techniques.

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.

553. Concrete Materials and Technology. *Prerequisite: Civ. Eng. 351.* I. *(2).*
Physical-chemical behavior of plastic concrete and fundamental concepts of hardened concrete microstructure relating to strength, volume change, permeability, creep, and durability. Recent developments in use of admixtures for set-control, water reduction, expansion, shrinkage compensation, retardation, or acceleration, etc.; autoclaving masonry products; and fabrication of special aggregate-cement structural units. Lecture and laboratory.

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 of 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.* 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.* II. *(2).*
Theory of least squares, applications to the adjustments 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.* II. *(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 Planning 570). Urban Transportation. *Prerequisite: senior or graduate standing.* II. *(3).*
Principles of urban transportation planning. An examination of urban transportation systems and their relationship to land use and the social, economic, and political structure of cities. Not open to graduate students in highway, traffic, and transportation engineering.

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.

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

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

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

579. Special Problems in Transportation. *Prerequisite: permission of instructor.* I, II, and III*a*. *(1-3).*
Advanced problems selected from the broad area of transportation engineering, including railroads, airports, highways, traffic and mass transportation.

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

581. Environmental and Water Chemistry. *Prerequisite: Chem. 103 or 104.* I. *(3).*
Homogeneous and heterogeneous chemical and biochemical equilibria in lakes, rivers, estuaries, and other natural waters; in water and wastewater treatment processes; and in other systems of concern in environmental engineering and pollution control. Principles and techniques of methods for analysis of water, wastewater, air, and solid wastes.

582. Sanitary Engineering Design. *Prerequisite: Math. 216 and Civ. Eng. 481.* I. *(3).*
General methods of design and their application to water and wastewater treatment processes and other environmental systems. Theory and practice of aeration and gas transfer. Principles of reaction tank design. Mathematical and analog simulation of water and wastewater treatment systems.

583. Water Purification and Treatment. *Prerequisite: Civ. Eng. 480.* II. *(3).*
Engineering methods and devices for obtaining and improving the sanitary quality and economic value of water supplies; processes of sedimentation, use of coagulants, filtration, softening, iron removal, sterilization; devices and structures for accomplishing these objectives. Lectures, library reading, and visits to muncipal water purification plants.

584. Waste Water Treatment and Disposal. *Prerequisite: Civ. Eng. 481.* 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: 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 treatment and satisfactory disposal of these wastes.

587(Chem. Met. Eng. 584) (Microb. 584). Industrial Bacteriology. *Prerequisite: Civ. Eng. 580.* II. *(3).*
Lectures and demonstrations to illustrate the application of microbiological principles and techniques to industrial processes.

588. Environmental and Water Resource Systems and Economics. *Prerequisite: a course in statistics.* I. *(3).*
Introduction to the concepts of systems analysis and related topics as applied to environmental and water resources problems. Use of decision theory and mathematical programming techniques. Cost benefit analysis, resource economics, and analytical modeling in contemporary environmental and water quality problems.

589. Political Factors in Environmental and Water Resources Engineering. *Prerequisite: senior or graduate standing.* II. *(3).*
Introduction to aspects of the political process relevant to resource allocation problems; consideration of political bargaining and decision making, the nature of political power, characteristics of a technical-oriented bureaucracy, the engineering political interface. Readings in water resource problems; term papers may reflect other areas of individual professional interest. Computer simulation of political interaction.

590. Stream Analysis. *Prerequisite: Math. 216 and Civ. Eng. 481.* I. *(3).*
Introductory principles of mass transport and material balance. Characteristics and distribution of contaminants in waterways. Effects of biological oxygen demand, reaeration, sludge deposits, nitrification, and aquatic plants. Mathematical models describing oxygen resources in streams. Demonstrations of practical problems.

591. Unit Operations in Environmental and Water Resources Engineering. *Prerequisite: Civ. Eng. 581.* II. *(3).*
Unit operations for treatment of water, air, and solid wastes. Laboratory studies of adsorption, biochemical and chemical oxidations; coagulation and sedimentation; combustion; distillation; electrodialysis and reverse osmosis; filtration, gas transfer, and ion exchange and softening.

610(Nav. Arch. 610). Finite Element Methods. *Prerequisite: Eng. 102, and Nav. Arch. 510 or Civ. Eng. 512.* II. *(3).*
Matrix methods. Influence coefficients. Analysis of member systems by the displacement and force methods. Element stiffness matrices. Development of the finite element method—the derivation of the element stiffness matrices for plane stress and plate bending—and its application to plates and shells. Computer 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.* 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 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.* 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.

624. Free Surface Flow. *Prerequisite: Civ. Eng. 523.* 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 lateral inflows. Unsteady free surface flow in porous media. Simulation techniques using the digital computer.

629. Hydraulic Transients II. *Prerequisite: Civ. Eng. 529.* 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 systems.

645. Theoretical Soil Mechanics. *Prerequisite: permission of instructor.* I. *(3).*
Stress conditions for failure in soils; earth pressures and retaining walls; arching in soils; theories for elastic and plastic deformations of soil masses; theory of bearing capacity; theories for stresses in semi-infinite and layered elastic solids; theory of elastic subgrade reaction.

648. Dynamics of Soils and Foundations. *Prerequisite: Civ. Eng. 445.* *(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.

649. Soil Dynamics Laboratory. *Prerequisite: preceded or accompanied by Civ. Eng. 648.* II. *(1).*
Field and laboratory instrumentation for dynamic measurements; field and laboratory determination of dynamic soil properties; measurement and analysis of foundation vibrations. Laboratory.

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.* II. *(3).*
Planning transportation facilities. Studies and analytical techniques used in estimating transportation demand. Evaluating alternative transportation systems.

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.* 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.

680. Microbiology II. *Prerequisite: Civ. Eng. 580.* 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 Processes in Environmental and Water Resources Engineering. *Prerequisite: Civ. Eng. 581.* II. *(3).*
Rate processes, separation processes, and surface phenomena in natural waters, and water and waste treatment operations; energetics and kinetics of chemical and biochemical processes; chemical and biochemical oxidations; gas transfer; corrosion; electrochemical processes; sorption and exchange reactions, particle growth kinetics and coagulation phenomena.

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 Environmental and Water Resources Engineering. *Prerequisite: permission of instructor.* I, II, III*a* and III*b*. *(To be arranged).*
Special problems designed to develop perspective and depth of comprehension in selected areas of sanitary, environmental, or water resources 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: permission of instructor.* II. *(3).*
Application of operations research technique in environmental and water resources engineering; mathematical programming and optimization procedure, stochastic description of environmental systems, queueing and inventory models; development of mathematical models for describing environmental and water resource systems. Decision theory techniques.

780. Water Resource Engineering. II. *(3).*
Conservation and protection of sources of water supply; laws governing appropriation and use of water resources as affecting both quantity and quality; standards of water quality, purposes and results of water purification; legal rights and responsibilities of public water utilities. Text and library reading, lectures, and seminar.

810. Structural Engineering Seminar. I and II. *(1).*
Preparation and presentation of reports covering assigned subjects.

825. Seminar in Hydraulic Engineering. *Prerequisite: Civ. Eng. 420 and 523. (To be arranged).*
Lectures, assigned reading, and student reports on problems selected from the field of hydraulic engineering.

870. 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.

875. Highway Engineering Seminar. *Prerequisite: graduate standing.* I and II. *(1).*
Seminar dealing with highway design, materials and construction. Lectures, assigned reading and student reports.

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: permisson 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. Transportation Engineering Research. *Prerequisite: permission of instructor.* I, II, III*a* and III*b*. *(To be arranged).*
Individual research and reports on library, laboratory, or field studies in the areas of transportation and traffic engineering.

975. Highway Engineering Research. *Prerequisite: permission of instructor.* I, II, III*a* and III*b*. *(To be arranged).*
Individually assigned work in the field of highway engineering.

980. Environmental and Water Resoures Engineering Research. *Prerequisite: permission of instructor.* I, II, III*a*, and III*b*. *(To be arranged).*
A research study of some problems relating to water resource development and water supply, waste treatment and pollution control, or sanitation and environmental health; a wide range of both subject matter and method is available, including field investigations, laboratory experimentation, library and public record searches, and engineering design work.

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.

Computer, Information and Control Engineering

Program Office: 1512 East Engineering
See page 112 for statement on Course Equivalence.

412(Elec. Eng. 412). Engineering Probability and Statistics. *Prerequisite: Math. 216 (3).*
Basic concepts of probability theory: random variables, probability distributions, averages, moments, characteristic functions, independence. Binomial, Poisson, and Gaussian distributions. Introduction to statistical inference and its applications in engineering; statistics of measurements; confidence intervals; least square fitting of data.

450(Elec. Eng. 450). Feedback Control I. *Prerequisite: preceded or accompanied by Math. 448 or Elec. Eng. 300. (2).*
The concept and advantages of feedback control in continuous-time systems. Transfer functions, block diagrams and signal flow graphs. Transient and steadystate response of linear control systems; stability considerations; design philosophies and criteria. Use of Nyquis, Bode and root-locus methods for analysis and synthesis. Not open to students with credit for Elec. Eng. 350, Aero. Eng. 471, or equivalent.

451(Elec. Eng. 451). Feedback Control Laboratory I. *Prerequisite: preceded or accompanied by C.I.C.E. 450 or Elec. Eng. 350. (1).*
Introduction to the analog computer and its application to control system simulation and design. Experiments with physical systems. Design examples and the use of digital computation to aid design. Not open to students with credit for Elec. Eng. 351, Aero. Eng. 471, or equivalent.

452(Elec. Eng. 452). Nonlinear and Sampled-Data Control Systems. *Prerequisite: Elec. Eng. 350, Aero. Eng. 471, or C.I.C.E. 450. (3).*
Introduction to sampling and discrete-time systems; sampling and data reconstruction; z-transforms; analysis and design procedures for sampled-data systems. Sensitivity consideration in control system design. Introduction to nonlinear systems; phase plane analysis; describing functions; stability. Formulation of optimal control problems, simple examples of optimal control systems.

453(Elec. Eng. 453). Feedback Control Laboratory II. *Prerequisite: Elec. Eng. 351 or C.I.C.E. 451, and preceded or accompanied by Elec. Eng. (C.I.C.E.) 452. (1).*
Experiments involving sampling and sampled-data feedback systems. Project experiments to be selected from content of Elec. Eng. (C.I.C.E.) 452.

460. Digital Computers and Computation. I and II. *(4).*
Introduction to the important hardware and software concepts of digital computation. The laboratory which is part of the course involves programming and logical design. Students who have taken Elec. Eng. 365, Elec. Eng. 366 and Com. Comm. Sci. 473 or some equivalent sequence should not elect this course.

467(Elec. Eng. 467). Introduction to Switching Theory. *(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.

470. Systems Programming. *Prerequisite: Com. Comm. Sci. 473, and Elec. Eng. 365.* I and II. *(3).*
The technique of constructing systems programs: operating systems, input-output systems, interpreters and compilers for higher-level languages. Parsing algorithms and problems of syntactic analysis and semantic interpretation.

472. Nonnumeric Computations. *Prerequisite: Com. Comm. Sci. 473.* I and II. *(3).*
The description, representation and manipulation of arrays, lists, trees, graphs, and other combinatorial structures; design of list processing systems; searching and sorting algorithms.

482(Elec. Eng. 482). Applications of the Analog Computer. *Prerequisite: Math. 216, or 316, or 404. (3).*
Basic theory and principles of operation of analog computers. 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 analog computer.

500. Linear Dynamical Systems. *Prerequisite: Math. 448 or Elec. Eng. 300 and preceded or accompanied by Math. 417 or 513. (3).*
Models of dynamical systems: difference and differential equations, linearty, time-invariance, concept of state, examples. Input-output relations: integral operators and transfer functions. Solution forms for linear dynamical systems: fundamental matrix and variation of parameters formula, exponential matrix, Floquet theory, adjoint equations, numerical methods. Stability: definitions, methods of analysis, examples. Algebraic theory: state equivalence, reducibility, controllability and observability, canonical decompositions.

501. Function Space Methods in Systems Science. *Prerequisite: preceded or accompanied by C.I.C.E. 500.* I and II. *(3).*
An introduction to the analysis of dynamic systems using the concepts of sets, function spaces, and operators to analyze continuous, discrete and distributed systems. Emphasis is placed on the use of function-theoretic concepts for the analysis of system structure, system canonical forms and other fundamental system properties. Specific topics include a review of the spaces L_p, l_p, C(a,b) and applications.

504. Introduction to Nonlinear Dynamical Systems. *Prerequisite: C.I.C.E. 500. (3).*
Differential equations, existence and uniqueness of solutions, solution properties. The phase plane: equilibrium points and their classification, geometric techniques, index theory, theorems of Bendixson. Conservative systems, limit cycles, jump phenomena, Lienard equation. Stability and introduction to direct method of Lyapunov. Forced systems. Applications.

506. Large-Scale Systems I. *Prerequisite: C.I.C.E. 412. (3).*
Discrete parameter Markov chains. Modeling of large-scale systems as Markov chains. Systems of queues and servers subjected to negative exponential, Erlang and hyper-exponential distributions. Dynamic programming and other methods of determining optimum policies for systems governed by Markov chains.

510. Stochastic Processes I. *Prerequisite: C.I.C.E. 412. (3).*
The concept of a stochastic process. The special cases of discrete-parameter and continuous-parameter processes. Gaussian processes. Correlation functions. Stationary processes; ergodic properties and spectral theory. Response of a linear system to a stochastic process. Introduction to spectral estimation. Least-mean-square error linear filtering and prediction. Examples and applications in control and communication.

520. Basic Communications. *Prerequisite: C.I.C.E. 510. (3).*
Fundamentals of representation and analysis of continuous and discrete signaling methods. Discrete methods include binary and arbitrary base transmission, coherent and incoherent reception, statistically optimum decision receivers, and the relationships among signal-to-noise ratio, bandwidth, signaling rate, error probabilities and channel capacity. Continuous modulation and multiplex theory emphasizes spectral occupancy, signal-to-noise ratio improvement, crosstalk, and improvement thresholds for AM, FM, PM, PAM, PDM, PPM, and multiplexed PCM.

522. Voice Communication Systems. *Prerequisite: preceded or accompanied by C.I.C.E. 520. (2).*
Methods of analog and digital recording and reproduction of natural voice treated with respect to information transmission and natural quality. Vocoder-based techniques, companding, non-linear PCM, delta modulation, data compression, external encoding, and predictive techniques.

525. Coding for Communication Systems. *Prerequisite: preceded or accompanied by C.I.C.E. 520. (2).*
Coding of discrete signals for analog channels having various characteristics. Error detecting and correcting codes. Topics include cyclic block codes, convolutional codes, threshold decoding and sequential decoding. Implementation and performance are emphasized.

530. Information Theory. *Prerequisite: C.I.C.E. 412. (3).*
The concepts of source, channel, rate of transmission of information. Entropy and mutual information and their properties. Encoding and the noiseless coding theorem. The coding theorem for finite-state, zero-memory channels. Gaussian channels; definitions, properties and coding theorems. Error bounds. Source encoding. Introduction to group codes.

540. Optimal Control I. *Prerequisite: C.I.C.E. 500. (3).*
Formulation of optimal control problems. Dynamic programming, Hamilton-Jacobi theory, linear problems with quadratic criteria, the Ricatti equation. The Pontryagin principle, application to the design of a variety of physical systems. Introduction to computational methods.

550. Feedback Control II. *Prerequisite: C.I.C.E. 450 or Elec. Eng. 350 or Aero. Eng. 471. (2).*
Nonlinear control systems. Piecewise linear analysis. The phase plane and phase space: analysis of system motion; determination of sliding and oscillatory behavior; nonlinear controller design and effect of controller imperfection; simple examples of optimal control systems. The describing function. Stability determination by methods of Lyapunov and Popov. Sensitivity to parameter changes and disturbance inputs.

551. Laboratory Projects in Control. *Prerequisite: preceded or accompanied by C.I.C.E. 550 or C.I.C.E. 552. (1).*
Directed laboratory projects based on the material in C.I.C.E. 550 and C.I.C.E. 552.

552. Sampled-Data Control Systems. *Prerequisite: C.I.C.E. 450 or Elec. Eng. 350 or Aero. Eng. 471. (2).*
Technological reasons for sampling. Sampling processes and their mathematical description. The z-transform and its application to the analysis of mixed-data systems. Steady state and transient response; methods for stability determination. Application of classical design procedures; finite settling time designs. Digital computer realization of compensators; effects of quantizing errors. Use of state space methods for analysis and design of systems with complex sampling processes.

565. Logical Design of Digital Computers. *Prerequisite: C.I.C.E. 560 and C.I.C.E. 467. May be replaced by Elec. Eng. 365, Elec. Eng. 366, Com. Comm Sci. 473. (3).*
Advanced course in logical design. Logical properties of devices. Discussion of specific logical designs for arithmetic, micro-programming, generation of special functions, hash addressing, etc. Use of the digital computer as an aid in logical design and to the problems of design automation.

566. Laboratory in Logical Design. *Prerequisite: C.I.C.E. 565. (2).*
Laboratory experience in logical design of computer systems and in the development of appropriate programs and algorithms for computer-aided design.

567. Switching and Automata Theory. *Prerequisite: C.I.C.E. 467.* I and II. *(3).*
Sequential machine theory, including machine decomposition, regular expressions, state identification experiments. Design of networks with unreliable components. Algorithms for switching circuit analysis and design.

569. Digital Computer Arithmetic. *Prerequisite: C.I.C.E. 560 or Elec. Eng. 365 and C.I.C.E. 467. (3).*
Classification and structure of finite number systems and arithmetic, including the weighted, redundant and signed digit classes of number systems. Theory of complement coding. Theory of modern computer arithmetic including fast carry logic, multiplier coding, Booth's method of multiplication and R.S.T. division. Codes for the detection and correction of arithmetic errors.

572(Ind. Eng. 512). Combinatorial Optimization Methods. *Prerequisite: C.I.C.E. 467 or Com. Comm. Sci. 522 or Ind. Eng. 510 or Math. 518. (3).*
An introduction to mathematical methods of combinatorial optimization, including those derived from dynamic programming, unimodular linear programming, matroid theory, and partial enumeration. Applications to systems analysis and design including problems of sequencing, scheduling, assignment, clustering, diagnosis, and classification.

580. Introduction to Hybrid Computation. *Prerequisite: C.I.C.E. 482. (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 a variety of engineering problems such as parameter optimization and partial differential equations. Lecture and laboratory.

606. Large-Scale Systems II. *Prerequisite: C.I.C.E. 506. (3).*
Principles of direct and sophisticated Monte Carlo methods. Applications to solution of linear operator equations and analysis of large-scale systems. Use of computer simulation languages.

610. Stochastic Processes II. *Prerequisite: C.I.C.E. 510. (3).*
Representations of second order stochastic processes using Hilbert space concepts. Further material on least-mean-square error filtering, linear and non-linear. Non-linear operations on Gaussian processes. Poisson and related processes; application to shot noise; Markov processes; introduction to diffusion processes and stochastic differential equations.

612. Recursive Filtering. *Prerequisite: C.I.C.E. 510 and C.I.C.E. 540. (2).*
Linear dynamical systems excited by white noise as models for discrete and continuous time random processes; recursive linear (Kalman-Bucy) filtering of random processes corrupted by additive noise, prediction and smoothing solutions; relation to deterministic optimal control, relations of controlability and observability to filtering; some relations of filtering to information theory; stochastic optimal control; separation of estimation and stochastic optimal control; applications.

620. Signal Detection. *Prerequisite: C.I.C.E. 412 or C.I.C.E. 510.* I. *(3).*
Likelihood ratio theory for binary forced-choice decisions, and reduction of uncertainty through observation. Simple-composite hypothesis theory applied to cases of signals with various levels of uncertainty in known added Gaussian noise. Interaction of uncertainty and noise on the design and performance of optimum detectors. Doubly composite hypothesis theory applied to cases where there is also uncertainty as to the noise process. The role of adaptation or learning in the design of full-memory optimum detectors.

621. Signal Estimation: Demodulation and Measurement. *Prerequisite: C.I.C.E. 520. (2).*
Structures for optimum demodulation in accordance with various criteria. Evaluation of optimum and suboptimum demodulator performance. Synchronizers for time-division multiplexing. Estimation in measurement systems.

623. Space Communication Systems. *Prerequisite: C.I.C.E. 520. (2).*
Consideration of communication systems operating over great distances. Technological and statistical communication aspects of design.

624. Relay-Satellite Communication Systems. *Prerequisite: C.I.C.E. 520. (2).*
The use of satellite relays for terrestrial communication. System design considerations including the multiple access problem.

630. Theory of Coding. *Prerequisite: Math. 513 or 417 and C.I.C.E. 530. (3).*
Theory and design of group, cyclic, convolution, concatenated and arithmetic codes and pseudo-random sequences. Galois field theory. Hamming, Reed-Muller, Reed-Solomon, BCH and Fire codes.

640. Optimal Control II. *Prerequisite: C.I.C.E. 501, C.I.C.E. 540. (3).*
Introduction to mathematical programming, proof of Pontryagin principle for discrete and continuous-time problems. Sufficient conditions. Existence theory. Computational methods. Miscellaneous topics.

641. Function Space Optimization Methods. *Prerequisite: C.I.C.E. 540 and C.I.C.E. 501. (3).*
An introduction to the use of topological, geometric and function space methods for optimization in a generalized system setting. Problems of optimal control, pursuit evasion games, and system optimization are emphasized, with applications to distributive, discrete and continuous systems; optimal linear systems and the relationship between optimality and system sensitivity.

644. Stability of Dynamical Systems. *Prerequisite: C.I.C.E. 504, preceded or accompanied by C.I.C.E. 501. (2).*
Lyapunov theorems and their application to autonomous and non-autonomous systems. Linear time varying systems. Derivation and application of the Popov condition. Miscellaneous topics. Applications to control.

650. Advanced Applications in Control. *Prerequisite: permission of instructor. (3).*
Selected topics of current interest relating to control system applications.

665. Systems Design of Digital Computers. *Prerequisite: C.I.C.E. 565 and Com. Comm. Sci. 573. (3).*
General consideration of computer architecture with attention being given to both the hardware and the software. Memory hierarchies, look ahead, multi processing and time sharing.

668(Com. Comm. Sci. 622). Algebraic Theory of Automata. *Prerequisite: Com. Comm. Sci. 522 or Elec. Eng. 467, and Math. 517 or Math. 513.* I. *(3).*
The use of algebraic techniques in the study of the relation between structure and behavior; decomposition of sequential machines probabilistic automata and various special automata; topics such as the relation of automata theory to coding theory and to mathematical linguistics.

699. Directed Individual Study. *Prerequisite: permission of instructor. (To be arranged).*

701. Special Topics in System Science. *Prerequisite: permission of instructor. (To be arranged).*

704. Special Topics in Nonlinear Systems. *Prerequisite: permission of instructor. (To be arranged).*

710. Special Topics in Stochastic Processes. *Prerequisite: permission of instructor. (To be arranged).*

720. Special Topics in Communication Theory. *Prerequisite: permission of instructor. (To be arranged).*

730. Special Topics in Information Theory. *Prerequisite: permission of instructor. (To be arranged).*

740. Special Topics in Control Theory. *Prerequisite: permission of instructor. (To be arranged).*

765. Special Topics in Computer Engineering. *Prerequisite: permission of instructor. (To be arranged).*

767. Special Topics in Switching and Automata Theory. *Prerequisite: permission of instructor. (To be arranged).*

770. Special Topics in Computer Programming. *Prerequisite: permission of instructor.* I. *(To be arranged).*
Topics to be arranged.

775(Elec. Eng. 775). Special Topics in Simulation and Computer Aided Design. *Prerequisite: permission of instructor.* I. *(To be arranged).*
Topics to be arranged.

801. Seminar in System Theory. *Prerequisite: permission of instructor. (To be arranged).*

804. Seminar in Nonlinear Systems. *Prerequisite: permission of instructor. (To be arranged).*

810. Seminar in Stochastic Processes. *Prerequisite: permission of instructor. (To be arranged).*

820. Seminar in Communication Theory. *Prerequisite: permission of instructor. (To be arranged).*

830. Seminar in Information Theory. *Prerequisite: permission of instructor. (To be arranged).*

840. Seminar in Control Theory. *(To be arranged).*

865. Seminar in Computer Engineering. *Prerequisite: permission of instructor. (To be arranged).*

867. Seminar in Switching and Automata Theory. *Prerequisite: permission of instructor. (To be arranged).*

870. Seminar in Computer Programming. *Prerequisite: permission of instructor.* II. *(To be arranged).*
Topics to be arranged.

875(Elec. Eng. 875). Seminar in Simulation and Computer Aided Design. II. *(To be arranged).*
Topics to be arranged.

990. Thesis. *Prerequisite: permission of instructor. (To be arranged).*

*Economics**

Department Office: 105 Economics Building

Professor Smith, Chairman; Professor Cross, Associate Chairman; Professors Ackley, W. H. L. Anderson, Barlow, Berg, Bornstein, Brazer, A. Eckstein, Fusfeld, Haber, Hymans, Katona, Levinson, Morgan, Mueller, Palmer, Porter, Scherer, Shapiro, Smith, Steiner, Stern, Stolper, Winter; Associate Professors G. Anderson, Cross, Dernberger, Feldstein, Holbrook, Johnson, Newell, Shepherd, Struempel, Taylor, Teigen; Assistant Professors Cohen, P. Eckstein, Hill, Klass, Manove, Neenan, Shoup, Simmons, Stafford, Wertz; Lecturers Crafton, Deardorff, Freedman, Lee, Pope, Saxonhouse, 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.

400. 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.

* College of Literature, Science, and the Arts.

B. Advanced Courses

410. Money and the Economy. *Prerequisite: Econ. 201 and 202.* II. *(3).*
A general course on the structure of financial institutions and the role of money in the economy. Emphasis is placed on important contemporary problems in the area of monetary and fiscal policy.

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.

450. Comparative Economic Systems. *Prerequisite: Econ. 201 and 202. (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.

405. Economic Statistics. *Prerequisite: Econ. 201 and 202.* I and II. *(3).*
Introduction to the principal methods of statistical analysis as applied to economic problems.

480. Public Finance. *Prerequisite: Econ. 201 and 202.* I. *(3).*
A survey of government expenditure and revenue issues, designed for students wishing to take a single comprehensive course in the field of public finance.

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
See Page 112 for statement on Course Equivalence.

200. Introduction to Electrical Engineering. *Prerequisite: preceded or accompanied by Physics 240. (2).*
Orients the student in the major areas of electrical engineering. Basic concepts and applications to modern electrical systems and devices. Lectures and demonstrations. Not open to electrical engineering students beyond the sophomore level.

211. Resistive Network Analysis. *Prerequisite: Engr. 102 and Math. 117.* I and II. *(3).*
Linear and nonlinear resistive network analysis. Kirchhoff's laws, mesh and node analysis, elementary graph theory, network theorems; two-port analysis; computer-aided modeling and solution of nonlinear resistive networks. Two lectures and a computation 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.

300(Math. 300). Mathematical Methods in System Analysis. *Prerequisite: Math. 216. (3).*
The elements of complex analysis; Fourier, Laplace, and z transforms, with emphasis on their application to linear, differential and difference equations with constant coefficients.

305(Math. 305). Mathematical Methods of Field Analysis. *Prerequisite: Math. 216. (3).*
Vector differential and integral calculus. Line, surface and volume integrals. Fourier series and orthogonal functions. Solution of partial differential equations (e.g., Laplace's equation, the wave equation) by separation of variables with emphasis on engineering applications.

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.

311. Dynamic Network Analysis. *Prerequisite: Elec. Eng. 211, Math. 216, accompanied by Elec. Eng. 300. (2).*
Linear and nonlinear dynamic network analysis. Analysis of waveforms; state formulation and solution of simple linear networks; numerical solution of nonlinear networks; s-plane methods for steady state and transient network analysis.

312. Electronic Circuits I. *Prerequisite: Elec. Eng. 311. (3).*
Large- and small-signal models of diodes and transistors; linear and nonlinear analysis of basic electronic circuits; rectification, amplification, modulation, oscillation; basic switching and logic circuits.

314. Circuit Analysis and Electronics. *Prerequisite: Math. 316 and Physics 240. (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 performance. Lecture-demonstration and two-hour laboratory. Not open to electrical engineering or science engineering students.

320. Electromagnetics. *Prerequisite: preceded by Elec. Eng. 215, Physics 240, 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; semiconductors; ferromagnetism; magnetic circuits; electromagnetic induction; Maxwell's equations; plane electromagnetic waves. Three lectures and one three-hour laboratory.

325. Electromagnetic Field Theory I. *Prerequisite: Physics 240, Engr. 102, and preceded or accompanied by Elec. Eng. 305. (4).*
Vector fields. Electrostatics and magnetostatics. Ampere's and Faraday's laws. Electromotive force; transformation between electric and magnetic fields. Maxwell's theory of electromagnetism. Foundations of circuit theory. Electromagnetic waves; transmission-lines.

326. (420). Electromagnetic Field Theory II. *Prerequisite: Elec. Eng. 325. (3).*
Cartesian tensor notation, stress tensor, Green's function; wave and Helmholtz equations, boundary conditions, e-m waves, polarization, normal and oblique incidence, dispersion, anisotropic media; guided waves, modes, rectangular and circular waveguides, resonant cavities; radiation, simple antennas.

330. Electronics and Communications. *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.

331. Electrical Circuits Laboratory. *Prerequisite: Elec. Eng. 311. (2).*
Electrical circuit measurement theory. Laboratory techniques; laboratory instruments. Voltage, current, impedance, transient, and device measurements leading to the design and testing of simple circuits. One lecture and one three-hour laboratory.

337. Electronic Circuits. *Prerequisite: Elec. Eng. 215. (4).*
Characteristics of electronic devices and analysis of circuits using them; diode rectifiers and filters, function generators, limiting and peaking circuits, basic amplifiers and coupling networks; feedback and stability, phase shift and negative resistance oscillator circuits, relaxation oscillators; amplitude, frequency, and pulse modulation and detection. Lectures and laboratory.

343. Energy Conversion. *Prerequisite: Elec. Eng. 300 and 325. (3).*
A unified treatment of elementary energy conversion devices based on the concept of coupled systems and energy state functions. Applications to transformers, fuel cells, ferroelectric and magnetocaloric devices, elementary electro-mechanical systems, and thermoelectric converters. Introduction to fluid energy conversion.

350. Linear Systems and Control. *Prerequisite: Elec. Eng. 300. (3).*
Transient and steady-state analysis of continuous-time systems; block diagrams; signal flow graphs; state variables; canonical forms. Basic objectives of control. Stability in stationary linear systems; Nyquist criterion; Routh test; root locus techniques. Relation of root locus, Nyquist and Bode diagrams to time response and design criteria. System design.

351. Control Systems Laboratory. *Prerequisite: Elec. Eng. 350. (2).*
Introduction to the use of analog and digital computers for the simulation of physical systems; experiments on typical elementary control systems; introduction to feedback system design; use of computer aids for design. One lecture and one three-hour laboratory.

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.

363. Measurements and Instrumentation. *Prerequisite: Elec. Eng. 325, Elec. Eng. 311, and Elec. Eng. 331. (3).*
Measurement of circuit parameters, electric and magnetic fields, characteristics of discrete and integrated devices. Basic concepts of modern instrumentation. Two lectures and laboratory.

365. Digital Computer Engineering. *Prerequisite: junior standing. (4).*
Internal organization of digital computers; basic digital logic; control processor organization; input/output devices; interrupt facility; data channels; storage devices; machine language; studies of existing systems. Lectures and laboratory.

366. Digital Computer Engineering Laboratory. *Prerequisite: Elec. Eng. 365. (2).*
Introduction to the practical aspects of designing digital computers using modern electronic components. Experiments with specially designed laboratory facilities. Lecture and laboratory.

380. Principles of Physical Electronics. *Prerequisite: Elec. Eng. 210 or 311 or 314 and 325, 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: Elec. Eng. 310 or 331, and preceded or accompanied by Elec. Eng. 380. (2).*
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 semi-conductors; junction characteristics; transistor characteristics. One lecture and one three-hour laboratory.

400. Computational Methods in Electrical Engineering. *Prerequisite: Eng. 102, Elec. Eng. 300 and 305. (4).*
Introduction to numerical methods for analysis and design with applications to problems of electrical engineering; computer solution of linear and nonlinear algebraic equations, ordinary differential equations, partial differential equations; fast Fourier transforms; optimization by gradient and search techniques; three lectures and computational laboratory.

410. Distributed Circuits. *Prerequisite: Elec. Eng. 325, and 310 or 311. (3).*
Distributed parameter circuits including coaxial and strip lines; electromagnetic waves on transmission lines, transient and steady-state analysis; reflections; impedance measurement and impedance matching, Smith chart; thin-film distributed circuits and applications; multi-conductor lines.

411. Electronic Circuits II. *Prerequisite: Elec. Eng. 312. (4).*
Advanced analysis and design of electronic circuits. Emphasis on practical design considerations and the use of integrated circuits as circuit elements. Two lectures and laboratory.

412(C.I.C.E. 412). Engineering Probability and Statistics. *Prerequisite: Math. 216. (3).*
Basic concepts of probability theory; random variables, probability distributions, averages, moments, characteristic functions, independence. Binomial, Poisson, and Gaussian distributions. Introduction to statistical inference and its applications in engineering; statistics of measurements; confidence intervals; least square fitting of data.

415. Network Analysis and Synthesis. *Prerequisite: Elec. Eng. 310 or 311. (2).*
Topological network analysis; two-port parameters including scattering parameters; introduction to realizability theory; elementary synthesis.

421. Fields and Optics Laboratory. *Prerequisite: Elec. Eng. 325. (2).*
Experiments designed to demonstrate the properties and behavior of electromagnetic fields in waveguides and transmission lines; antennas. EM wave interaction with conducting and non-conducting materials. Experiments in optics include the use of lasers in the study of phenomena such as reflection, refraction, interference and diffraction.

422. Electromagnetic and Sonic Field Effects on Living Tissue. *Prerequisite: Elec. Eng. 325. (3).*
Electrical characteristics of various types of tissue; thermal effects of waves in tissue; waves through layered media; modeling of tissue layers; generation of e.m.f.'s by the heart; current flow through the body; alterations to tissue and organs due to irradiation by electromagnetic waves; sonic echoes from organs and changes of structure; ultrasonic waves for the stimulation of tissue and for diagnostics.

425. Electrodynamics. *Prerequisite: Elec. Eng. 325. (3).*
Quasi-static electric and magnetic fields; terminal relations and energy equations for lumped electrical and mechanical elements; dynamics of electromechanical systems; electromagnetic fields in moving systems; electric and magnetic force densities and surface stresses; dynamics of distributed electromechanical systems.

426. Electrodynamics of Solids and Fluids. *Prerequisite: Elec. Eng. 425. (3).*
Introduction to mechanics of solids and fluids; calculation of electrical forces on solid and fluid media; dynamics of solids with emphasis on wave motion with electrical coupling; applications to magnetostrictive, piezoelectric, and acoustic phenomena; dynamics of fluids with electrical coupling; applications to electrohydrodynamics and magnetohydrodynamics.

428. Antenna Theory I. *Prerequisite: Elec. Eng. 326 or 420. (3).*
Integration of Maxwell equations; nature of far-zoned 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.

430. Statistical Communication Theory. *Prerequisite: Elec. Eng. 312 or 314 or 330 or 337. (3).*
Signal transmission through electric networks; probability theory; basic concepts of information theory; an introduction to decision theory and optimum linear filtering.

432. Modulation Signals and Circuits. *Prerequisite: Math. 450 or Elec. Eng. 300. (3).*
Mathematical analysis of the signals and circuits used in present communication systems; basic spectral analysis, amplitude, phase, frequency, and pulse modulation; modulation and demodulation circuits; multiplexing, noise spectrum and circuit noise considerations; signal-to-noise ratio analysis for each type of modulation; applications to radio and television stressed throughout.

433. Electroacoustics. *Prerequisite: Elec. Eng. 215 or 311 or 314. (2 or 3).*
Electroacoustical analogs; lumped and distributed systems; transducers; sound recording; acoustic instrumentation and measurements. Lectures and optional laboratory.

441. Energy Conversion and Control Laboratory. *Prerequisite: preceded or accompanied by Elec. Eng. 444. (2).*
Laboratory experiments and projects; electromechanical and direct-conversion devices, control of power machinery by solid-state controlled rectifiers, and basic control systems utilizing electromechanical devices. Projects vary according to the interests of students and staff.

442. Instrumentation. *Prerequisite: Elec. Eng. 314 and 315, or 363. (3).*
Instrumentation methods for the measurement and recording of time, frequency, temperature, acceleration, pressure, noise, etc. Information storage techniques. Introduction to transducers, motors, and motor control. Advanced instrumentation for spectral analysis and correlation. Logical design and instrumentation. Two lectures and laboratory. Cannot be elected for graduate credit by Electrical Engineering students.

444. Control of Electromechanical Systems. *Prerequisite: Elec. Eng. 343 or 425. (3).*
A general treatment of electromechanical energy systems including solid-state power circuits, relay control, magnetic amplifiers and static switches. Utilization of system techniques; linear and nonlinear methods of analysis, and computer simulation. Lectures and demonstration.

448. Fundamentals of Power System Analysis. *Prerequisite: Elec. Eng. 311. (3).*
Power system functions and configurations; representation of power systems; network theory: matrix and graph theory applied to electric networks, computer algorithms for network formation; formulation of the load-flow problem and solution by digital computer.

450(C.I.C.E. 450). Feedback Control I. *Prequisite: preceded or accompanied by Math. 448 or Elec. Eng. 300. (2).*
The concept and advantages of feedback control in continuous-time systems. Transfer functions, block diagrams and signal flow graphs. Transient and steady-state response of linear control systems; stability considerations; design philosophies and criteria. Use of Nyquist, Bode and root-locus methods for analysis and synthesis. Not open to students with credit for Elec. Eng. 350, Aero. Eng. 471, or equivalent.

451(C.I.C.E. 451). Feedback Control Laboratory I. *Prerequisite: preceded or accompanied by C.I.C.E. 450 or Elec. Eng. 350. (1).*
Introduction to the analog computer and its application to control system simulation and design. Experiments with physical systems. Design examples and the use of digital computation to aid design. Not open to students with credit for Elec. Eng. 351, Aero. Eng. 471, or equivalent.

452(C.I.C.E. 452). Nonlinear and Sampled-Data Control Systems. *Prerequisite: Elec. Eng. 350, Aero. Eng. 471, or C.I.C.E. 450. (3).*
Introduction to sampling and discrete-time systems; sampling and data reconstruction; z-transforms; analysis and design procedures for sampled-data systems. Sensitivity consideration in control system design. Introduction to nonlinear systems; phase plane analysis; describing functions; stability. Formulation of optimal control problems, simple examples of optimal control systems.

453(C.I.C.E. 453). Feedback Control Laboratory II. *Prerequisite: Elec. Eng. 351 or C.I.C.E. 451, and preceded or accompanied by Elec. Eng. (C.I.C.E.) 452. (1).*
Experiments involving sampling and sampled-data feedback systems. Project experiments to be selected from content of Elec. Eng. (C.I.C.E.) 452.

466. Digital Design Laboratory. *Prerequisite: Elec. Eng. 312 and Elec. Eng. 366. (2).*
Realistic design problems in digital system engineering. Design, construction, and demonstration of devices which operate alone or in conjunction with digital computers in the laboratory. Lecture and laboratory.

467(C.I.C.E. 467). Introduction to Switching Theory. *(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.

470. Fundamentals of Electrical Design. *Prerequisite: Elec. Eng. 210 and 325. (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.

471(Bioeng. 471). Electrical Biophysics. *Prerequisite: Elec. Eng. 311 or 314 or 215. (3).* Electrical biophysics of muscle, nerve and synapse. Hodgkin-Huxley equation, electrical conduction in excitable tissue, phase plane analysis and modeling of neural elements, semiconductor characteristics of biological membranes, biopotential mapping and biological noise.

472. Principles of Electrical Design. *Prerequisite: Elec. Eng. 311 and 325. (3).* Analytical and computational tools and concepts; application to modeling and analysis of electrical systems. Decision making, logical design, design evaluation. Linear programming, fundamentals of optimization (incorporating economic constraints). Case studies.

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: Elec. Eng. 300 or preceded or accompanied by Math. 450. (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; ultransonic 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 I. *Prerequisite: senior standing in engineering or physical science. (3).*
Theory and instrumentation for sensing and measuring light and infrared radiation; topics include blackbody radiation (Kirchhoff's and Stefan's laws), reflection 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.

477. Coherent Optics Laboratory. *Prerequisite: Elec. Eng. 475. (2).*
Experimental aspects and techniques of coherent optics. Lasers, alignment techniques for optical systems, characteristics of photographic recording materials, spatial filtering, coherent imaging, interferometry and coherence measurement of light sources; holography. Lecture and laboratory.

480. Microwave and Quantum Electronic Devices. *Prerequisite: Elec. Eng. 380 and 326 or 410. (3).*
Electron beam transit-time effects; velocity modulation and electron bunching; space-charge waves on electron beams; coupled modes of propagation; principles of operation of linear beam amplifiers and oscillators (TWA, klystron, etc.), parametric amplifiers, masers, lasers; introduction to the Gunn-effect and IMPATT diode theory. Lectures and demonstrations.

482(C.I.C.E. 482). Applications of the Analog Computer. *Prerequisite: Math. 216, or 316, or 404. (3).*
Basic theory and principles of operation of analog computers. 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 analog computer.

483. Solid-State Electronics. *Prerequisite: Elec. Eng. 380. (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.

484. Solid State Devices Laboratory. *Prerequisite: Elec. Eng. 483. (2).*
Semiconductor material and device fabrication and testing. Diode fabrication; wafer preparation; contact application; evaluation of semiconductor properties. Evaluation of diode electrical characteristics and their relationship to junction properties. Bipolar and field-effect transistor fabrication and evaluation.

485. Integrated Electronics. *Prerequisite: Elec. Eng. 381 and either Elec. Eng. 330 or 312. (3).*
Types of integrated circuits; physical processes employed in the design of integrated circuits; impurity diffusion and diffused-junction properties; oxidation and surface states; thin-film deposition and properties; epitaxial growth; passive and active components for integrated electronics; integrated circuit design principles.

486. Integrated Circuits Laboratory. *Prerequisite: Elec. Eng. 485. (2).*
Integrated circuit fabrication; mask design; photographic reduction; photoresist application, exposure, development and etching; oxidation; diffusion; metal film deposition by evaporation and sputtering; die bonding, wire bonding and encapsulation; testing of completed integrated circuit.

490. Special Topics in Electrical Engineering. *Prerequisite; senior standing in Electrical Engineering. (To be arranged).*
Topics of current interest selected by the faculty. Lecture, seminar or laboratory.

495. Thermosphere and Ionosphere. *Prerequisite: senior standing in engineering or physical science. (3).*
Basic physical processes significant to the structure and characteristics of the upper atmosphere; photochemistry, diffusion, ionization; distribution of neutral and charged particles; thermal structure of the upper atmosphere; atmospheric motions, geomagnetic storms.

499. Directed Research Problems. *Prerequisite: senior standing in Electrical Engineering. (To be arranged).*
Individual study of selected topics in electrical engineering. May include experimental investigation or library research. Primarily for undergraduates.

515. Network Synthesis. *Prerequisite: Elec. Eng. 415. (3).*
Properties of network functions; realizability theory; synthesis of driving-point and transfer impedances; approximation techniques.

520. Electromagnetic Field Theory III. *Prerequisite: Elec. Eng. 326, and 305 or 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.

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 II. *Prerequisite: Elec. Eng. 428. (3).*
Integral equations of perfectly conducting antennas, techniques of solutions and application to cylindrical and slot antennas. Frequency independent antennas, broadband loaded antennas. Radiators in lossy and ionized media. Antenna synthesis, realizability, optimization; use of orthogonal functions in synthesis problem. Signal processing antennas.

530. Microwaves I. *Prerequisite: Elec. Eng. 326 or 410. (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. 326 or 410, and Elec. Eng. 305 or 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. 330 or 312. (3).*
Review of probability fundamentals. Stationary random processes; time and frequency domain properties. Transmission of noise through linear and nonlinear systems. Physical aspects of shot noise and thermal noise. Noise temperature and noise factor. Noise generation in electronic tubes and solid state devices. Noise in microwave, infrared and optical systems.

535(Astron. 535). Astronomical Radiophysics. *Prerequisite: Elec. Eng. 326. (3).*
Review of electromagnetic theory. Propagation of radio waves through ionized media. Radiation by elementary dipoles and accelerated charges; emission and absorption in ionized media including thermal, Cerenkov, and synchrotron mechanisms. The emphasis is on astronomical rather than engineering applications.

536(Astron. 536). Introduction to Radio Astronomy. *Prerequisite: Elec. Eng. 535. (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 sources, amplifiers, and detectors. Theory and use of the spectrum analyzer and sampling oscilloscope. Selected experiments on traveling-wave amplifiers, tunnel diode amplifiers, Gunn-effect devices, and IMPATT diodes. Lecture and laboratory.

539. Electronic Circuit Design. *Prerequisite: Math. 404 or 450, Elec. Eng. 330. (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. Electromechanical Energy Conversion. *Prerequisite: Elec. Eng. 444. (3).*
Synchronous and induction machines. Machine dynamics, dqo transformation; faults; unbalanced voltages; hunting; damping; time and space harmonics; stability; sequence impedance; governor characteristics; voltage regulation.

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. Analysis of Three-Phase Systems. *Prerequisite: Elec. Eng. 448. (3).*
Analysis of a-c and d-c transmission lines; voltage regulation and compensation; corona and radio influence; matrix analysis of three-phase networks: incidence and network matrices, computer algorithms for formation of network matrices, application to three-phase fault studies.

554. Unbalanced Faults and System Stability. *Prerequisite: Elec. Eng. 448. (3).*
Co-ordinate transformations for unbalanced networks: symmetrical components, Clarke's components; computer algorithms for formation of unbalanced network matrices; application to fault studies; formulation and solution of the steady state and transient stability problems.

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: Elec. Eng. 410. (2).*
Steady-state and transient fault voltages; lightning and switching surge phenomena; attenuation, reflection, and distortion on transmission lines; computer solution for transient voltages and currents; wave propagation in machine windings; system surge protection and insulation co-ordination.

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.

571(Bioeng. 571). Introduction to Neurophysiological Systems. *Prerequisite: Elec. Eng. 350 or C.I.C.E. 450. (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(Bioeng. 573) (Zoology 573). Bioelectrical Measurements. *Prerequisite: mathematics, physics, and chemistry; graduate standing; and permission of instructor. (4).*
Techniques and problems associated with measurements from biological systems. Topics to be covered include electrodes, transducers, bioeletric 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. 326. (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. (3).*
Special topics of current research interest in the field of electro-optical sciences.

576. Noncoherent Optical Technology II. *Prerequisite: Elec. Eng. 476. (3).*
Spectroradiometric laboratory and field measurement instrumentation and techniques; optical systems with reflective, refractive and catadioptric objectives; Fourier interferometry and spectroscopy; cameras and photographic processes; imaging systems such as vidicons, orthicons and image dissectors; polarizers and analyzers; reflective, refractive and absorptive filters. Design of optical-mechanical imaging systems.

579. Coherent Optics Laboratory. *Prerequisite: preceded or accompanied by Elec. Eng. 475. (2).*
Experiments in optics including the study of diffraction, interference and image formation phenomena. The use of the Mark Zehnder interferometer for various optical measurements. Modification of images through spatial filtering techniques. Construction of spatial match filters for character recognition. Construction of holograms. The use of hologram interferometry.

580. Physical Processes in Plasmas. *Prerequisite: Elec. Eng. 380. (3).*
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 solid state and gaseous plasmas; microwave determination of plasma density and temperature.

581(Nuc. Eng. 575). Plasma Dynamics and Particle Optics Laboratory. *Prerequisite: preceded or accompanied by a course in plasmas or physical electronics. (3).*
Experimental techniques for plasma dynamics, electron and ion beam technology, and vacuum technology. Experiments will be on microwave and probe diagnostics of plasmas, plasma instabilities, vacuum systems, plasma generation, electron and ion beam generation and optics, and other topics of current interest. Lectures will be given for background material.

583. Quantum and Statistical Electronics. *Prerequisite: Elec. Eng. 326. (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.

590. Special Topics in Electrical Engineering. *Prerequisite: permission of instructor or counselor. (To be arranged).*
Topics of current interest in Electrical Engineering. Lectures, seminar, or laboratory. Can be taken more than once for credit.

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. Magnetosphere and Solar Wind. *Prerequisite: Elec. Eng. 580. (3).*
General principles of magnetohydrodynamics; theory of the expanding atmosphere; properties of the solar wind, interaction of the solar wind with the magnetosphere; bow shock and magnetotail, trapped particles, auroras.

615. Topics in Network Theory. *Prerequisite: Elec. Eng. 515. (To be arranged).*
Special topics in the analysis and synthesis of electrical networks.

617. Analytical Techniques for Communications Systems. *Prerequisite: Elec. Eng. 450 (C.I.C.E. 450) or 515. (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 IV. *Prerequisite: Elec. Eng. 520. (3).*
Individual and collective motions of charged particles in electromagnetic field. Absorption, propagation, scattering, and generation of radiation in plasmas. Least action and Fermat's principles, Eikonal Equations, and Hamilton's Canonical Equations of optics and mechanics. The concepts and techniques of Special Relativity and Lorentz Covariance are introduced.

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.

630. Microwaves II. *Prerequisite: Elec. Eng. 530. (3).*
General field theory for wave guides; the impedance concept and the application of network theory to microwave structures, general network theorems; analytical methods for determining equivalent circuits for microwave structures, the integral equation formulation. Green's function, variational techniques, and applications to typical boundary value problems; propagation in anisotropic media, nonreciprocal devices; the scattering matrix, and the analysis of multiport networks.

647. Introduction to Navigation Systems. *Prerequisite: Elec. Eng. 546. (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.

655. Optimization and Control of Integrated Power Systems. *Prerequisite: Math. 417 or Math. 513. (3).*
Optimization of constrained functions in finite-dimensional spaces, computational methods for solving optimization problems; formulation of the economic dispatch problem, solution by transmission loss formulae and by computer optimization; system and component dynamics, load and frequency control of interconnected systems.

680. Wave Propagation in Plasmas. *Prerequisite: Elec. Eng. 580 and 620. (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.

683. Quantum Electronic Devices. *Prerequisite: Elec. Eng. 583. (3).*
General principles of the laser; optical resonators; laser media, paramagnetic, gaseous, semiconductor and others; operational modes, Q-switching, short pulse generation. Harmonic generation and parametric interaction. Photon-photon interaction; optical modulation and demodulation.

687. Nonlinear Interaction Theory for Beams, Waves and Plasmas. *Prerequisite: Elec. Eng. 480, 580. (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 properties of bulk semiconductors and junctions; device applications including recent developments.

689. Noise in Microwave and Quantum Devices. *Prerequisite: Elec. Eng. 480.* II. *(2).*
Statistical mechanics of multistream systems; 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. (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.

691(Bioeng. 691) (Physiol. 691) (Zool. 691). Neurosciences Laboratory. *Prerequisite: preceded or accompanied by Physiol. 690 and permission of instructor. (2).*
Interdepartmental staff. Laboratory exercises and demonstrations in neurobiology.

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.

725. Radiation and Scattering. *Prerequisite: Elec. Eng. 620. (3).*
Survey of recent advances in the analysis of radiation and scattering phenomena such as direct scattering and inverse scattering; propagation in inhomogeneous, random or anisotropic media; non-linear propagation phenomena in electromagnetism and optics; applications.

775(C.I.C.E. 775). Special Topics in Simulation and Computer Aided Design. *Prerequisite: permission of instructor. (To be arranged).*
Topics to be arranged.

810(Astro. 810). Advanced Radio Astronomy Seminar. *Prerequisite: Elec. Eng. 536. (2).*

815. Seminar in Network Theory. *Prerequisite: Elec. Eng. 515. (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, anaysis and synthesis of time-varying networks, synthesis of active networks.

820. Seminar in Electromagnetic Field Theory. *Prerequisite: Elec. Eng. 620, or 428 and 530. (To be arranged).*
Study and discussion of current topics in electromagnetic field theory. This seminar may be repeated for credit.

830. Seminar in Microwave Theory. *Prerequisite: Elec. Eng. 530. (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 Application. *Prerequisite: Elec. Eng. 430 or 534. (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.

875(C.I.C.E. 875). *Seminar in Simulation and Computer Aided Design. Prerequisite: permission of instructor. (To be arranged).*
Topics to be arranged.

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(Aero. Eng. 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

See Page 112 for statement on Course Equivalence.

All undergraduate degree programs in the College of Engineering will accept up to four credit hours of elective courses from this group as free and/or technical electives.

101. Graphics. *(2).*
Elementary graphical communications using both freehand and instrument techniques to treat such topics as multiview and pictorial representations, auxiliary views, sections, dimensions and tolerances, and lettering.

102. Digital Computing. *(2).*
Flow diagrams, algorithms, and digital computer programming, application of numerical methods such as root finding, interpolation, integration, simultaneous equations and simple optimum-seeking techniques in engineering problems.

110. Computer Graphics. *(4).*
Computers and graphics presented in an integrated computer-augmented design context; geometric construction and transformation; principles of drafting and projections; analysis and synthesis of graphical information; dimensioned and scaled drawings in design.

120. Engineering Concepts and Computations. *Prerequisite: high school chemistry and physics. (4).*
Engineering concepts are presented to provide a basis for solving a variety of problems to give perspective, orientation, and foundation for the study of engineering. Parallel presentations introduce computing, algorithms, programming, and techniques of problem solving. Problems solved by slide rule, graphs, and digital computer. Three lectures, two recitations.

155(Mat.-Met. Eng. 155). Materials and Civilization. *Prerequisite: Chem. 103.* II. *(2). Not open to students having had Mat.-Met. Eng. 250.*
The history of materials of industry and their impacts on civilization—past, present, and future. The nature of the technological advances that affect social changes.

190. History of Engineering. *(3 or 4).*
A history of engineering and the development of technology from ancient times to modern. Major developments are surveyed with selected topics studied in depth. Emphasis is given to the impact on the life of the people. Students who elect the course for four credit hours will be required to do a special project.

195. Selected Topics in Engineering. *(To be arranged).*

270. Programming Languages and Algorithms. *Prerequisite: Eng. 102 or Eng. 110 or Eng. 120 or Math. 273.* I and II. *(3).*
Comparative study of programming languages: procedure oriented languages FORTRAN and ALGOL, list processing languages, problem oriented languages. Algorithmic concepts. Exercise in problem formulation and in the application of programming languages to representative numerical and nonnumeric problems. Lecture, recitation, and laboratory work in programming.

458(Geog. 458). Man's Impact on Environment. *Prerequisite: Humanities 338 or a 400-level course in environmental science.* I. *(3).*
Examine changes in the physical environment which are directly attributable to man and technology; determine the significance of these changes as they affect man and his culture today. Explore the extent to which some of these changes were unanticipated. Consider causes of unanticipated environmental change.

490. Special Topics in Engineering. *(To be arranged).*
Individual or group study of topics of current interest selected by the faculty.

Engineering Graphics—Under the Administration of the Mechanical Engineering Department

Graphics Faculty Office: 412 West Engineering
See Page 112 for statement on Course Equivalence.

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.

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. Mechanic 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 the 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. (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
See Page 112 for statement on Course Equivalence.

208. Statics. *Prerequisite: preceded by Math. 116 and Physics 140.* 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 Materials. *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.

211. Introduction to Solid Mechanics. *Prerequisite: Physics 140, Math. 116.* I, II and III*a*. *(4). Open to juniors and seniors with permission of instructor.*
Principles of statics including equilibrium and static equivalence. Determination of moment and force resultants in slender members. Introduction to mechanics of deformable bodies; concepts of stress and strain, classification of material behavior, stress-strain relations and generalized Hooke's law. Application to engineering problems involving members under axial load, torsion of circular rods and tubes, bending and shear stresses in beams, combined stresses, deflection of beams. Three lectures and one two-hour recitation-demonstration period.

212. Laboratory in Mehanics of Materials. *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 140, 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 140 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. 211.* 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. 340, or 218 and 345, and preceded or accompanied by Math. 316.* I. *(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(Civ. Eng. 324). Fluid Mechanics. *Prerequisite: Eng. Mech. 340, preceded or accompanied by Mech. Eng. 335.* I and II. *(3).*
Principles of mechanics applied to real and ideal fluids. Topics include fluid properties and statics; continuity, energy and momentum equations by control volume; dimensional analysis and similitude; laminar and turbulent flow; boundary layer, drag, lift; incompressible flow in pipes; free-surface flow; adiabatic flow of ideal gases in conduits; fluid measurement and turbomachinery.

326. Fluid Mechanics. *Prerequisite: Eng. Mech. 340 or 345, preceded or accompanied by Math. 316.* 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.

340. Introduction to Dynamics. *Prerequisite: Physics 140 and preceded or accompanied by Math. 216 or 316.* I, II, III*a* and III*b*. *(4).*
Vector description of force, position, velocity, and acceleration in fixed and moving reference frames. Force and couple resolution, and equilibrium concepts. Kinetics of particles, assemblies of particles and of rigid bodies, energy and momentum concepts. Euler's equations. Keplerian motion. Moment of inertia properties. The simple oscillator and its applications. Three lectures and one two-hour recitation-demonstration period.

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. 211 and 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. 211 and 340, and Elec. Eng. 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. 211.* 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 Materials. *Prerequisite: Eng. Mech. 211, preceded or accompanied by Math. 450.* 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.

422. Intermediate Mechanics of Fluids. *Prerequisite: Eng. Mech. 324, preceded or accompanied by Math. 450.* I and II. *(3).*
Fundamental concepts of theoretical fluid mechanics. Development and applications of 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 equation. Elements of hydrodynamic stability, turbulence, boundary layers, jets, wakes, drag.

442. Intermediate Dynamics. *Prerequisite: Eng. Mech. 340 and Math. 450.* 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.

460. Analytical Methods in Mechanics I. *Prerequisite: Eng. Mech. 211, Eng. Mech. 340 and Math. 216.* I. *(3).*
An introduction to the notation and techniques of vectors, tensors, and matrices as they apply to mechanics. Emphasis is on physical motivation of definitions and operations, and on their application to problems in mechanics. Extensive use is made of examples from mechanics.

503. History of Mechanics. *Prerequisite: Eng. Mech. 211 and 340.* II. *(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. The growth of continuum mechanics in the nineteenth century. The impact of relativity, wave mechanics, and modern mathematics.

507. Theory of a Continuous Medium. *Prerequisite: Eng. Mech. 412, 422.* II. *(3).*
The general theory of a continuous media. 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 with emphasis on viscoelastic fluid flow.

511(Aero. Eng. 514). Foundations of Structural Mechanics I. *Prerequisite: Eng. Mech. 414. (3).*
Elements of the analysis of structures. Includes plates of various shapes, loading and boundary conditions, effects of in-plane loading; shells of revolution, cylindrical shells, bending and membrane theories; plastic analysis of structures, beams, frames, plates; plastic collapse mechanism. Applications of aerospace interest.

512(Aero. Eng. 515). Foundations of Structural Mechanics II. *Prerequisite: Eng. Mech. 511. (3).*
Behavior of structures in a thermal environment, heat conduction, aerodynamic heating of high speed vehicles, thermal stresses and deflections, thermal instabilities, discussion of material properties at elevated temperature. Elements of the theory of linear viscoelasticity.

514. Theory of Elasticity I. *Prerequisite: Eng. Mech. 412.* 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.* II. *(3).*
Classical linear plate theory, with application to various shapes, boundary conditions, and loading systems; refinements to account for anisotropy, shear deformations, large deflections; plastic collapse and elastic instability.

516. Theory of Shells I. *Prerequisite: Eng. Mech. 412.* I. *(3).*
General theory for deformation of thin shells with small deflections; various approximate theories, including the membrane theory. Application to various shell configurations.

517. Theory of Linear Viscoelasticity I. *Prerequisite: Eng. Mech. 412, Math. 447.* 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.* 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.* 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 Fliuds I. *Prerequisite: Eng. Mech. 422.* II. *(3).*
Theory of inviscid flows. Forces, moments, and the added mass tensor; application of conformed mapping; free streamline theory; flows with concentrated and distributed vorticity; linear wave theory; flow past slender bodies and wings; hodograph and Karman-Tsien methods for subsonic flows; method of characteristics; perturbation methods in high-speed flows.

523. Mechanics of Viscous Fliud I. *Prerequisite: Eng. Mech. 422.* I. *(3).*
Theory of viscous flows. Exact solutions of the Navier-Stokes equations; slow motion solutions; boundary layers; jets and wakes; forced and free convection flows; heat transfer and compressible boundary layers; hydrodynamic stability; statistical theories of turbulence; rotating flows; surface tension effects.

524. Wave Motion in Fluids. *Prerequisite: Eng. Mech. 422. (3).*
Surface waves in liquids, group velocity and dispersion; shallow water waves, kinematic waves, method of characteristics; subcritical and supercritical flows; analogy between free-surface flows and gas flows; subsonic flows of a gas, hodographs, Molenbroek's transformation, Legendre's transformation, Chaplygin's treatment, Karman-Tsien method; supersonic flows; Riemann's nonlinear treatment of finite waves, nonlinear expansion flows, Prandtl-Busemann method of characteristics; shock waves; wave motion of a conducting fluid in an electromagnetic field.

525. Non-Newtonian Fluid Mechanics. *Prerequisite: Eng. Mech. 324 or Chem. 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.

526(Meteor.-Ocean. 526). Dynamics of the Oceans and Atmosphere. *Prerequisite: preceded or accompanied by Eng. Mech. 422.* II. *(3).*
Dynamics of rotating stratified flow, the β-plane approximation; wave motions, geostrophic adjustment, Gulf Stream theory, and other topics of interest in geophysical fluid mechanics.

527. Thermodynamics. *Prerequisite: Math. 450.* 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.* 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. (3).*
Mathematical modelling and techniques for solving some problems in the bio-sciences: 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.* 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.

545. Vibrations of Continuous Media. *Prerequisite: Eng. Mech. 412 and 442.* 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. (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.* 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.

549(Aero. Eng. 549) (Mech. Eng. 549). Random Vibrations of Mechanical Systems. *Prerequisite: Eng. Mech. 340 or Eng. Mech. 343.* II. *(3).*
Random mechanical inputs: wind buffeting; earthquakes; surface irregularities. Engineering applications include response of a linear spring-mass system and an elastic beam to single and multiple random loading. Failure theories. Necessary concepts such as ensemble averages, correlation functions, stationary and ergodic random processes, power spectra, are developed heuristically.

555. Statistical Foundations of Mechanics. *Prerequisite: Eng. Mech. 324 and 340, and Math. 450.* 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 Materials I.** *(2).*

***573. Intermediate Mechanics of Materials II.** *(2).*

***574. Intermediate Mechanics of Fluids I.** *(2).*

***575. Intermediate Mechanics of Fluids II.** *(2).*

* For description see Eng. Mech. 412 and 422 or Detroit Extension Service bulletin.

626. Singular-Perturbation and Approximate Methods in the Mechanics of Fluids I. *Prerequisite: Eng. Mech. 422.* I. *(3).*
Application of asymptotic methods to fluid mechanics, with special emphasis on the method of matched expansions. Regular perturbation solutions; suppression of secular terms; method of multiple times; boundary layer and low Reynolds number flows by inner and outer expansions; phenomena in rotating flows; asymptotic solutions of the Orr-Sommerfeld equation.

627. Singular Perturbation and Approximate Methods in the Mechanics of Fluids II. *Prerequisite: Eng. Mech. 626.* II. *(3).*
Shock singular perturbation theory; matched expansion theory for potential flows; matched expansion theory in turbulent flows; substitute kernel methods as applied to fluid mechanics; modified Oseen method; Wiener-Hopf technique for mixed boundary value problems.

640. The Principles and Applications of Variational Methods. *Prerequisite: Eng. Mech. 442. (3).*
Fundamental processes of the calculus of variations; derivation of the Euler-Lagrange equations; proof of the fundamental lemma; applications of the direct method; Lagrange multipliers; "natural" boundary conditions; variable end points; Hamilton's canonical equations of motion; Hamilton-Jacobi equations. Descriptions of fields by variational principles. Applications to mechanics. Approximate methods.

680. Numerical Methods in Mechanics. *Prerequisite: one 500 level course in mechanics. (3).*
Matrix methods applied to the stiffness matrix, vibration analysis, and hydrodynamic stability. Solution of integral equations by collocation, variational methods, successive approximations; applications to elasticity, plates, slow viscous flow, and inviscid flow. Finite difference and finite increment methods; application to wave propagation, structural stability, plasticity, free-surface flows and wakes.

714. Theory of Elasticity II. *Prerequisite: Eng. Mech. 514.* I. *(3).*
Three-dimensional elasticity problems. Derivation of approximate system (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.* 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.* I. *(3).*
Treatment of hydrodynamic equations in general co-ordinates by tensorial methods; gravitational, hydromagnetic, and surface-tension instabilities; instability of rotating fluids and of flow in porous media. Tollmien-Schlichting waves; instability of free-surface flows.

741. Nonlinear Oscillations. *Prerequisite: Eng. Mech. 442, Math. 404 and 450.* 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 oscillations.

745. Wave Motion in Continuous Media. *Prerequisite: Math. 450.* II. *(3).*
Wave propagation in bounded and extended elastic media, including transmission, reflection, and refraction phenomena, transient-stress states, and analogies with acoustical and optical effects. Forced motion of continuous elastic systems such as plates, membranes, shells, and other forms.

801. Seminar in Engineering Mechanics. *Prerequisite: permission.* I and II. *(1 or 2).*
A series of weekly seminars. Students who contribute may elect one or two hours credit.

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. (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 fields 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.

*Geology and Mineralogy**

Department Office: 1006 C. C. Little

Professor Dorr; Professors Arnold, Briggs, Cloke, Eschman, Goddard, Heinrich, Hibbard, Hough, Kelly, Kesling, Pomeroy, Rhodes, and Wilson; Associate Professors Farrand, Macurda, Peacor, Pollack, and C. I. Smith; Assistant Professors Clark, Essene, Evans, and G. R. Smith.

* College of Literature, Science, and the Arts.

111. Introduction to Earth Science. *Not open to those who have had Geol. 116, 117, 218, or 219.* I. *(4).*
An introduction to science through geology. The study of the materials making up the earth, the processes which act upon them, and the effects these processes have on the earth's surface; the development of the tools for the interpretation of the history of the earth; and the major geologic concepts which make geology unique from the other natural sciences. One or more Saturday field trips will be required. Lectures, laboratory, and field trips for an average weekly total of seven hours.

218. Geology for Engineers. II. *(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. Lectures, laboratory, and campus field trips.

219. Geology and Man. *Not open to freshmen, nor to those who have had Geol. 111, 116, 117, 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, Evolution of the Earth and of Life, and also Geol. 280, Geology of Man's Mineral Resources, are especially useful for engineering students.

Humanities in the Department of Humanities

Department Office: 3516 Natural Resources
See page 112 for statement on Course Equivalence.

Normally a student will take four courses with the Department: two three-hour courses in Great Books during the freshman year, a three-hour Literature Seminar in the junior year, and three hours of rhetoric in the senior year.
In his work here and for other courses in the engineering curriculum the student is 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 Humanities, may prescribe additional study.

Humanities Electives

The Humanities Department offers a variety of courses in literature and public speaking, as well as interdisciplinary courses in art, music, and philosophy, which the student may elect to satisfy his humanities requirement. (See below.)

American Studies

The American Studies program, coordinated by the Department of Humanities, may be elected to satisfy both the humanities and social sciences requirements. This program is an interdisciplinary approach to the study of America's past and present. To increase their understanding and appreciation of American life and culture, students may concentrate in such subjects as American literature, history, art, political science, or sociology. Schedules leading to the completion of the American Studies sequence are worked out by the student in consultation with an adviser of the American Studies Committee of the Department of Humanities. Students wishing to enroll in the program should report to Room 3516 Natural Resources Building for an appointment with one of the program advisers: Professors Martin (Chairman), Holcombe, Stevenson, and Weeks.

The program is designed to begin in the sophomore year after the completion of Humanities 101 and 102 and will continue through the senior year, although a student may withdraw at any point.

Concentration Program. Eighteen to twenty-two hours, as recommended by the student's program adviser, including the following three Humanities courses required of all students in the program: 334, Survey of American Literature (3); 441, Major American Writers (3); 492, American Studies Seminar (3).

Distribution of Course Work. To complete the requirements in the humanities and social sciences, courses may be elected appropriate to the American Studies program in areas such as Anthropology, English, History, History of Art, Music, Philosophy, Political Science, Sociology, and Speech. Courses in areas not listed above may be included with the approval of an American Studies adviser.

Great Books

The courses in Great Books are intended to introduce the student to significant works that helped shape our culture, and thus provide background for his later study of the humanities and social sciences.

101. Great Books I. I, II and III*b*. *(3).*
Readings in literature, philosophy, and history selected from Homeric Greece to the time of Chaucer. Typical selections may include Homer's *Iliad,* Sophocles' *Oedipus,* Plato's *Apology,* Aristotle's *Ethics,* and Chaucer's *Canterbury Tales.* The course gives the student an opportunity to read major works and to write essays based on his reading.

102. Great Books II. *Prerequisite: Humanities 101.* I, II and III*a*. *(3).*
A continuation of Great Books I. Readings in major works from the time of Shakespeare. Typical selections may include Machiavelli's *The Prince,* Shakespeare's *Hamlet,* Voltaire's *Candide,* Goethe's *Faust,* and Thoreau's *Civil Disobedience.* The student reads major works and writes essays based on his reading.

Special Courses for Foreign Students

103. Composition for Foreign Students. I. *(3).*
A bridge between the student's language studies in his own country and the English Language Institute and subsequent work in courses designed primarily for American students. An intensive study of American English grammar and an introduction to rhetoric, particularly the rhetoric of smaller forms such as the sentence and paragraph.

104. Great Books for Foreign Students. *Prerequisite: Humanities 103.* II. *(3).*
Continues the study of rhetoric begun in Humanities 103. Writing problems are drawn from the reading and discussion of those great books that are the core texts in Humanities 101and102.

Humanities Electives

Sophomore standing is a prerequisite for the following 200- and 300-level humanities courses.
The following courses are available to satisfy the humanities requirement of the College of Engineering. These courses differ from the Literature Seminars by being more broadly inclusive or interdisciplinary.

199. Selected Topics. *Prerequisite: permission of instructor.* I and II. *(1 to 3).*
Study of selected topics, to be announced whenever the course is offered.

201. Selected Topics. *Prerequisite: permission of instructor.* I and II. *(1 to 3).*
Study of selected topics, to be announced whenever the course is offered.

224. Modern Poetry. I, II, III*a* and III*b*. *(2)*.
Analysis of influential poetry, mainly of the 20th century, emphasizing distinctive techniques and attitudes of authors such as Yeats, Eliot, Frost, Thomas, Williams, Lowell, and Ginsberg.

225. Biography and Autobiography. I, II, III*a* and III*b*. *(2)*.
Reading and discussion of various forms of biographical writings: biographies, autobiographies, journals, letters, and diaries of such figures as Caesar, Jesus, Samuel Johnson, Napoleon, Van Gogh, Joyce, Hitler, Einstein, F. Scott Fitzgerald, and Malcolm X.

233. Modern Fiction. I, II, III*a*, and III*b*. *(3)*.
Analysis of influential fiction, mainly of the 20th century, emphasizing distinctive techniques and attitudes of authors such as James, Lawrence, Faulkner, Bellow, Mailer, Salinger, and Camus.

234. Modern Drama. I, II, III*a* and III*b*. *(3)*.
Analysis of influential drama, mainly of the 20th century, emphasizing distinctive techniques and attitudes of authors such as Ibsen, Chekhov, Strindberg, Pirandello, Beckett, Genet, Miller, Pinter, and Albee.

236. Cinema. I, II, III*a* and III*b*. *(3)*.
An exploration of the rhetoric of film, how sound and animated images are used to present an attitude toward reality, and how storytelling in film is embodied in the films of directors such as Eisenstein, Griffith, Renoir, Satajait Ray, Antonioni, Godard, and Hawks.

237. Literature and Philosophy. I, II, III*a* and III*b*. *(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.

238. Literature and Art. I, II, III*a* and III*b*. *(3)*.
A study of the relationship between the literature of a given period and its painting, sculpture, and architecture. Greek, Renaissance, and 20th century literature, painting, architecture, and sculpture will be studied for their similarities in purpose and style and for their value as expressions of the historical aims of their times.

239. Quest for Utopia. I, II, III*a* and III*b*. *(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 evaluate the present order.

301. Selected Topics. *Prerequisite: permission of instructor.* I and II. *(1 to 3)*.
Study of selected topics, to be announced whenever the course is offered.

324. Practice in Argument and Debate. I and II. *(2)*.
Controversial public issues, both current and persistent, will be analyzed through library research and consultation with experts. Students will organize and deliver oral arguments designed to lead the audience to a well-informed decision.

326. Major Speeches in American History. I, II, III*a* and III*b*. *(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.

327. American Folklore. I, II, III*a* and III*b*. *(2)*.
The sources and development in the United States of folktales, folk music, rituals, and superstitions of various occupational, ethnic and regional groups, and of particular

historic eras. An examination of such subjects as the stories and songs of the cowboys, miners, lumbermen, railroad men, and fishermen; the adaptation of Scottish border music to the Southern Appalachians; the development of jazz and gospel music from field chants.

328. Literature and Social Change. I, II, III*a* and III*b*. *(2)*.
The effect of scientific, economic, political, or cultural change upon literature, with particular reference to the 19th and 20th centuries. Among topics studied in any given term may be the following: science and poetry, politics and the modern novel; or the focus may be on a particular theme (e.g., urbanization and the theme of alienation in modern literature).

329. Opera as Drama. I, II, III*a* and III*b*. *(2)*.
A comparison of operatic masterpieces with their literary originals. An analysis of structure, characterization, tabuleaux and groupings, dramatic uses of the aria, chorus, and orchestra in such works as Purcell's *Fairy Queen,* Verdi's *Otello,* and Bernstein's *West Side Story* (from Shakespeare); Strauss's *Elektra* (from Sophocles and Hofmannsthal) or *Salome* (from Wilde); Weill's *Three Penny Opera* from John Gay and Brecht) and Poulenc's *Les Mamelles de Teresias* (from Apollinaire).

330. Great Works. *Prerequisite: freshman composition.* I and II. *(3)*.
Designed primarily for transfer students who have not taken Great Books. Readings in literature, philosophy, and history from the Greeks to 1915. Typical works may include Homer's *Iliad,* Chaucer's *Canterbury Tales,* Shakespeare's *Hamlet,* and Voltaire's *Candide.* Not open to students who have had Humanities 101, 102, or 104.

331. Literature of the Sea. I and II. *(3)*.
Selected readings of literary, historical, and scientific significance related to the sea and seafaring life. Readings will include authors and works such as Homer's *Odyssey,* Melville's *Moby Dick,* Verne's *20,000 Leagues Under the Sea,* Conrad's *Mirror of the Sea,* Hemingway's *Old Man and the Sea,* and Cousteau's *The Silent World.*

332. Literature of the American Pioneer. I and II. *(3)*.
A consideration of the westward movement of settlement; the causes, the trials of the trail and resettlement, the reaction against pioneer values and culture, and the effect of the loss of the frontier. Representative writers: Cooper, Eggleston, Garland, Rolvaag, Cather, Sandoz, and Wright Morris.

333. American Art. I, II, III*a* and III*b*. *(3)*.
A study of art in American life from colonial times to the present. The relationship of painting, architecture, and sculpture to the evolution of American culture as seen in the works of such figures as Saint Gaudens, Calder, Cole, Eakins, Wyeth, and Rothko.

334. American Literature. I, II, III*a* and III*b*. *(3)*.
A survey of American writing from the colonial period to the present. The course concentrates on 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.

335. European Literature. I, II, III*a* and III*b*. *(3)*.
Reading and analysis of major works in the European literary tradition from the 17th to the early 20th century. In any given term this course will focus upon British literature, or upon Continental literature in translation (chiefly French, German and Russian).

336. Black Literature in America. I, II, III*a* and III*b*. *(3)*.
An examination of major literary works in the several genres by Black American writers. This course supplements the study of black writers in conventional survey courses in American literature. Such authors as Langston Hughes, Leroi Jones, James Baldwin, Richard Wright, and Ralph Ellison will be studied.

337. Literature and Modern Thought. I, II, III*a* and III*b*. *(3).*
The three objectives of the course are: (1) to acquaint the student with some major forces of 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 that expresses and comments upon them.

338. Literature of Science. I, II, III*a* and III*b*. *(3).*
Reading and discussion of classics of scientific literature, such as Darwin's *Origin of Species* and Freud's *General Introduction to Psychoanalysis,* as well as writings by contemporary scientists on the scientific method, its application in various fields, and its limitations. The course deepens the student's awareness of the impact of science on man's conception of himself, his society, and his place in the universe.

339. Theory and Practice of Argument. I, II, III, III*a* and III*b*. *(3).*
Practice in developing and evaluating arguments. Various strategies of argument will be studied, particularly classical and Rogerian argument. Although some written work will be required, oral work will be emphasized.

375. Directed Study. *Prerequisite: permission of Humanities Department.* I, II, III*a* and III*b*. *(1 to 3).*
Conferences and tutorial sessions. Provides an opportunity for students with special interests or special problems to work under individual supervision and in close contact with the instructor.

401. Selected Topics. *Prerequisite: permission of instructor.* I and II. *(1 to 3).*
Study of selected topics, to be announced whenever the course is offered.

405. Adapting to Change. *Prerequisite: junior standing.* II. *(2 or 3).*
An interdisciplinary study of change and human responses to change. A theory of change will be developed and applied to a variety of systems (theoretical, psychological, environmental). Guest lecturers and readings (e.g., Gardner's *Self Renewal* and Kuhn's *Structure of Scientific Revolutions)* supplement class discussions, individual research projects and papers.

Seminars in Literature

These courses explore in depth an important but limited segment of the broad terrain covered by the Great Books courses. An integrated selection of significant works will be examined intensively in small classes through discussions and written assignments.

421. Chaucer. *Prerequisite: junior standing.* I, II, III*a* and III*b*. *(3).*
A detailed study of *The Canterbury Tales* and other works, such as *Troilus and Criseyde,* to emphasize, through modern translations, the lasting relevance of Chaucer's perceptive art.

422. Shakespeare. *Prerequisite: junior standing.* I, II, III*a* and III*b*. *(3).*
A detailed study of selected plays, including some of the great tragedies, to illustrate the depth and variety of Shakespeare's insight, thought, and art.

430. Major Continental Writers. *Prerequisite: junior standing.* I, II, III*a* and III*b*. *(3).*
An intensive analysis of the works of two or three influential authors, e.g., Voltaire, Goethe, Tolstoy, Mann, or Sartre.

436. Major British Writers. *Prerequisite: junior standing.* I, II, III*a* and III*b*. *(3).*
An intensive analysis of the work of two or three influential authors: e.g., Milton, Swift, Fielding, Blake, Wordsworth, Browning, Dickens, or Lawrence.

441. Major American Writers. *Prerequisite: junior standing.* I, II, III*a* and III*b*. *(3).*
An intensive analysis of the work of two or three influential authors: e.g., Hawthorne, Whitman, Twain, Hemingway, Faulkner, or O'Neill.

442. Literary Criticism: Comedy. *Prerequisite: junior standing.* I, II, III*a* and III*b*. *(3).*
A critical analysis of the comic spirit: in theory, as formulated by writers such as Aristotle, Freud, Meredith, or Bergson; in practice, as illustrated by writers such as Molière, Swift, Austen, or Ionesco.

454. Literary Criticism: Tragedy. *Prerequisite: junior standing.* I, II, III*a* and III*b*. *(3).*
A critical analysis of literature as profound expression of man's character, conflicts, and values. Works by authors such as Sophocles, Racine, Hardy, and Camus will be studied against a background of critical theory as formulated by writers such as Aristotle, Hegel, or Nietzsche.

460. Poetry. *Prerequisite: junior standing.* I, II, III*a* and III*b*. *(3).*
An examination of poetic forms, themes, or movements (in the works of such authors as Donne, Keats, Baudelaire, or e.e. cummings) in order to develop a critical awareness of the poem as an expression of human insight.

464. Drama. *Prerequisite: junior standing.* I, II, III*a* and III*b*. *(3).*
An examination of dramatic forms, themes, or movements (in the work of such authors as Jonson, Congreve, Shaw or Brecht) in order to develop a critical awareness of the drama as an expression of human insight.

466. Fiction. *Prerequisite: junior standing.* I, II, III*a* and III*b*. *(3).*
An examination of fictional forms, themes, or movements (in the works of such authors as Fielding, Conrad, Dostoevsky, or Joyce) in order to develop a critical awareness of fiction as an expression of human insight.

Seminars in Rhetoric

The following courses provide the senior and graduate student with intensive training in writing and speaking.

492. Seminar in American Studies. *Prerequisite: permission of the instructor.* I and II. *(3).*
Analysis and discussion of a selected topic from an interdisciplinary perspective. Independent reading and class discussions directed toward the production of oral and written compositions resulting from the student's cumulative experience in the American Studies program. Required in the senior year of those electing the American Studies program.

497. Seminar in Writing and Speaking. *Prerequisite: senior standing.* I, II, III*a* and III*b*. *(3).*
This course aims to increase proficiency in composition through study of rhetorical principles and writing problems, through analysis of models, and through concentrated practice in writing and speaking.

499. Scientific and Technical Communication. *Prerequisite: senior or graduate standing.* I, II and III*a*. *(3).*
The fundamentals of scientific and technical communication, both spoken and written, with emphasis on clear, precise, and orderly exposition.

Industrial Engineering

Department Office: 231 West Engineering
See page 112 for statement on Course Equivalence.

300. Introduction to Operating Systems. *Prerequisite: Math. 215.* I and II. *(3).*
Analysis of methods and concepts involved in the operation of profit and nonprofit organizations, including organization design, control, communication, and economic analysis. A model of an economic system has been programmed to allow study of the dynamic aspects of industrial decisions.

310. Operations Research. *Prerequisite: Math. 215.* I and II. *(3).*
An introduction to deterministic models in operations research with special emphasis on linear programming; the simplex, transportation, and assignment algorithms and their engineering applications. Brief introduction to integer, dynamic, and other nonlinear programming models.

315. Stochastic Industrial Processes. *Prerequisite: Stat. 310.* 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 engineering applications.

333. Human Performance. *Prerequisite: Eng. Mech. 211.* I and II. *(3).*
Introduction to the functional processes of the human system that pertain to an understanding of the limitations of humans in man-machine systems. Psychology, physiology, human factors, ergonomics, and engineering in the context of understanding and predicting human performance.

373. Data Processing. *Prerequisite: Eng. 102.* I and II. *(3).*
Introduction to the system organization and programming aspects of modern digital computers. Internal representation of numbers and number systems, logic, introduction to the concepts of time-sharing techniques, assembler and compiler writing, and simple data structures. Examples drawn from managerial and applied science areas, programmed in both assembly and compiler languages.

***400. Industrial Management.** 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. Intended for seniors and graduate students; sophomores and juniors should elect Ind. Eng. 300; not open to students who have received credit for Ind. Eng. 300.

401. Introduction to Management Sciences. *Prerequisite: Ind. Eng. 310 and 315.* II. *(3).*
Current studies in management problems, including management games, management design and control of research programs, organization and information theories.

415. Stochastic Industrial Processes. *Prerequisite: Stat. 310.* I and II. *(3).*
Study of basic stochastic processes encountered in modelling industrial situations. Discrete and continuous parameter Markov processes with discrete and continuous parameter state spaces. Renewal theory. Semi-Markov processes. Wald's identity. Central limit theorem for Markov chains. Not open for students with credit for Ind. Eng. 315.

421. Operating Systems—Procedures and Practices I. *Prerequisite: Ind Eng. 300 and Math. 216.* I and II. *(3).*
A case study approach to administrative problems in inventory and production control, plant layout, material handling, union-management relations, and employee motivation.

432. Industrial Engineering Instrumentation Methods. *Prerequisite: Stat. 311.* II. *(3).*
The characteristics and use of analog and digital instrumentation applicable to industrial engineering problems. Statistical methods for developing system specifications. Applications in physiological, human performance, and production process measurements are considered.

* 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 Performance. *Prerequisite: Stat. 311.* I. *(3).*
Factors that affect motor and decision times, such as strength, endurance, body size, sex, and age, are presented in the context of typical industrial environments. This course is primarily intended for students who do not have a background in human performance, but who are interested in the design of man-machine systems. Not open to undergraduate industrial engineering students.

441. Production and Inventory Control. *Prerequisite: Ind. Eng. 310 and 315.* I and II. *(3).*
Models and techniques for managing inventory systems and for planning production. Topics include basic deterministic and probabilistic inventory models and extensions; production loading, planning, and smoothing; and sequencing problems.

447. Facility Planning. *Prerequisite: Ind. Eng. 310 and 315, and 373.* I and II. *(3).*
Theory and methodology for determining optimal capacity and location of production and service facilities. Elementary engineering and economic considerations in the application of material handling equipment.

***451. Engineering Economy I.** *Prerequisite: Ind. Eng. 300 and junior standing.* I and II. *(3).*
The economic analysis of management and engineering problems. Specific attention will be devoted to methods of costing, economic problems related to selection and retirement of capital assets, depreciation methods, methods of financing, and the economics of production estimating.

460. Decision Analysis I. *Prerequisite: Ind. Eng. 310, and 315 or 415.* II. *(3).*
An introduction to normative decision analysis and applications. Decision structures under different assumptions of information availability are analyzed. Basic elements of utility theory, decision strategies, game theory, and statistical design theory are presented. Applications include capital investment, bidding, purchasing, inspection, inventory, and diversification policies.

463. Work Measurements and Prediction. *Prerequisite: Ind. Eng. 333 and Stat. 310.* I and II. *(3).*
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.

466. Quality Control. *Prerequisite: Stat. 311.* II. *(3).*
Application of statistics and probability theory to the design and analysis of procedures for control of production processes. Topics include: sampling distributions; attribute and variables sampling; single, multiple, and sequential sampling tests; rectifying control procedures; measures of control and monitoring procedures.

471(Mech. Eng. 483). Numerical Control of Manufacturing Processes. *Prerequisite: Mech. Eng. 381 or Ind. Eng. 373 and Mech. Eng. 252.* I and 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.

472. Operations Research. *Prerequisite: preceded or accompanied by Stat. 310.* I and II. *(3).*
Introduction to operations research; the methodology of mathematical models and its application to various industrial problems, including queueing theory, game theory,

* Students not enrolled in the industrial engineering program and not presenting the usual prerequisite may elect these courses with permission of the department.

linear programming, inventory theory, and Monte Carlo processes. Two one-hour lectures and a two-hour recitation section. Not open to Industrial Engineering undergraduate students.

473. Information Processing Systems. *Prerequisite: Ind. Eng. 373.* I and II. *(3).*
Organization of major types of information processing systems. Programming languages (COBOL, PL/1). Basic data manipulation operations. Alternative system organizations. Techniques for evaluation of performance systems.

474(Bus. Ad. Stat. 474). Simulation. *Prerequisite: Ind. Eng. 373.* II. *(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; students will run simple simulations.

478. Computer Graphics I. *Prerequisite: Ind. Eng. 373.* II. *(3).*
Introduction to on-line programming systems and graphic input-output systems including cathode-ray tube devices, automatic drafting machines, and plotters. 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.

490. Directed Study, Research and Special Problems I. *Prerequisite: permission of department.* I, II, III, III*a* and III*b*. *(3 maximum).*
Individual or group study, design, or laboratory research in a field of interest to the student or group. Topics may be chosen from any area of industrial engineering including management, work measurement, systems, and procedures.

491. Special Topics in Industrial Engineering. *(To be arranged).*
Selected topics of current interest in industrial engineering.

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.

510(Math. 518, Stat. (Bus. Ad.) 518). Linear Programming I. *Prerequisite: Math. 417.* I, II and III. *(3).*
Formulation of problems from industry, government, etc. as linear programs. The simplex algorithm. Duality, complementary slackness theorems and economic interpretation of dual variables. Revised simplex method. Parametric programming, sensitivity analysis. Flow in networks. Transportation problem. Use of computer codes like MSUB.

511(Math. 562). Mathematical Programming with Applications. *Prerequisite: Ind. Eng. 510.* I. *(3).*
Convex quadratic programming, bimatrix games, and complementary pivot theory. Lagrange multiplier technique. Kuhn-Tucker equations. Combinatorial and integer programming, shortest routes on networks, project networks, critical path problems. Dynamic programming. Markovian programming. Emphasis on presentation of methods with applications.

512(C.I.C.E. 572). Combinatorial Optimization Methods. *Prerequisite: C.I.C.E. 467 or Com. Sci. 522 or Ind. Eng. 510 or Math. 518.* I. *(3).*
An introduction to mathematical methods or combinatorial optimization, including those derived from dynamic programming, unimodular linear programming, matroid theory, and partial enumeration. Applications to systems analysis and design including problems of sequencing, scheduling, assignment, clustering, diagnosis, and classification.

514. Dynamic Programming. *Prerequisite: Math. 450 or 451.* I. *(3).*
Multi-stage decision problems, additivity and the principle of optimality, optimal value function and the technique of dynamic programming. Functional equations and recursive optimization. Examples from equipment replacement, resource allocation, warehouse problems, shortest routes, knapsack problem, Fibonacci search, etc. Discrete-time variational problems, multi-stage games. Stochastic and adaptive sequential decision problems. Markovian Programming Problems.

516(Stat. 616). Queueing Theory I. *Prerequisite Ind. Eng. 315 or 415 or Stat. 576.* II. *(3).*
Theory and applications of queueing processes. The M/G/1 and M/M/s queues. Waiting time, queue length, busy period and output. Time-dependent methods, embedded chains and Monte Carlo methods.

521. Operating Systems—Procedures and Practices II. *Prerequisite: Ind. Eng. 421.* II. *(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.

522. Theories of Administration. *Prerequisite: Ind. Eng. 421 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.

533. Human Factors in Engineering Systems I. *Prerequisite: Ind. Eng. 463 or 433.* I. *(3).*
The application of human performance research to the optimization of man-machine systems. Design of commonly used prediction and training systems under random and constant demands, learning functions, the statistical distributions of the population concerning manual skills, and methods of evaluating human capabilities and attitudes.

534(Bioeng. 534). Biomechanics and Work Physiology. *Prerequisite: Ind. Eng. 333.* II. *(3).*
Limitations of the human body in coping with stressful situations. Concepts to be included are: skeletal muscle physiology and mechanics, skeletal articulation and mechanics, circulatory and pulmonary system function and limitations, and nervous system control and limitations.

540. Concepts in Mathematical Modelling of Large Scale Systems. *Prerequisite: Ind. Eng. 310, and 315 or 415.* I. *(3).*
Application of engineering, operations research, and economic concepts to operational analysis and planning for large scale systems. Practice in mathematical modelling and critical evaluation of various aspects of existing and proposed models of systems in the public and private sector.

541(Stat. Bus. Ad. 541). Analysis of Inventory Systems I. *Prerequisite: Ind. Eng. 315 or 415, and 310.* II. *(3).*
Methods for controlling single-item inventories. Continuous review and periodic review models, deterministic and probabilistic cases, dynamic programming formulations and their properties.

543. Theory of Scheduling. *Prerequisite: Ind. Eng. 310 and 315.* I. *(3).*
The problem of scheduling several tasks over time, including topics measures of performance, single-machine sequencing, flow shop scheduling, the job shop problem, and priority dispatching. Integer programming, dynamic programming and heuristic approaches to various problems are presented.

545. Reliability, Replacement, and Maintenance. *Prerequisite: Ind. Eng. 315 or 415.* I. *(3).*
Stochastic models of system reliability. Optimal policies for replacement, preventive maintenance, and redundancy.

546. Industrial Procurement. *Prerequisite: Ind. Eng. 300.* I. *(3).*
Consideration of proper selection of sources of supply, price, and value analysis. Standards and specifications. Purchasing department organization, buying policies. Case problems are presented and discussed in detail.

547. Plant Flow Analysis. *Prerequisite: Ind. Eng. 315 or 415, and 310.* II. *(3).*
The development and application of mathematical models for the analysis of problems arising in the location and allocation of capacity to facilities and transportation systems with non-linear cost functions.

551. Engineering Economy II. *Prerequisite: Ind. Eng. 451.* 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.

560. Decision Analysis II. *Prerequisite: Stat. 311 and Ind. Eng. 460.* I. *(3).*
Techniques and assumptions of modern decision theory are presented, with the objective of providing a base for application of the theory to applied 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.

563. Work Measurement and Prediction II. *Prerequisite: Ind. Eng. 463.* I and II. *(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. *Prerequisite: Stat. 311.* 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.

572. Optimization in General Systems. *Prerequisite: Ind. Eng. 373 and Math. 417.* 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. Design and Construction of Large-Scale Administrative Systems. *Prerequisite: Ind. Eng. 415 and 473.* I. *(3).*
Introduction to informal and formal techniques for design, construction, and operation of large-scale information processing systems in general administrative environ-

ments. Problem statement techniques; system design techniques and performance evaluation models using operations research methodology; generalized data systems applicable in management and industrial decision making; project management on such systems design and programming efforts. Group projects will involve design and implementation of a business or industrial engineering system on a digital computer.

575. Information Processing Techniques for Administrative Systems. *Prerequisite: Ind. Eng. 300 and 473.* II. *(3).*
Formal operations research models used in the study of information processing systems. Data structures, file organization, storage structures applicable to a large business or industrial engineering environment. Theory of languages, computer hardware, software and operating systems appropriate to management information systems. Human performance and human factors aspects of large scale information systems.

578. Computer Graphics II. *Prerequisite: Math. 473 or Ind. Eng. 478.* I. *(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, and plotters. Topics may be chosen from any engineering or allied discipline, provided that the study or project emphasizes the methodology of computer graphics.

590. Directed Study, Research and Special Problems II. *Prerequisite: Permission of Instructor.* I, II, III, and III*a* and III*b*. *(3 maximum).*
Continuation of Ind. Eng. 490.

591. Special Topics in Industrial Engineering. *(To be arranged).*
Selected topics of current interest in industrial engineering.

610(Math. 660). Linear Programming II. *Prerequisite: Ind. Eng. 510.* II. *(3).*
Primal-dual algorithm. Resolution of degeneracy, upper bounding. Variants of simplex method. Geometry of the simplex method, application of adjacent vertex methods in nonlinear programs, fractional linear programming. Decomposition principle, generalized linear programs. Linear programming under uncertainty. Ranking algorithms, fixed charge problem. Integer programming. Combinatorial problems.

611(Math. 663). Nonlinear Programming I. *Prerequisite: Ind. Eng. 510 and, Math. 594 or 490.* I. *(3).*
Theorems of alternatives for linear inequality systems. Convex sets and their properties. Convex and concave functions and their properties. Convex inequalities. Convex quadratic programming. Saddle problems, constraint qualifications and theorems relating saddle solutions to optimal solutions. Lagrange multipliers, Fritz John theorem. The equations, constraint qualification and the theorem of Kuhn-Tucker.

612. Network Flows. *Prerequisite: Ind. Eng. 510.* II. *(3).*
Flow problems on networks. Maximum flow minimum cut theorem. Labelling algorithm. Circulation and feasibility theorems. Sensitivity analysis. Incidence matrices. Shortest routes. Minimum cost flows, out-of-kilter algorithm. Critical path networks, project cost curves. Multicommodity flow problem, biflows. Matching problems in graph theory.

613(Math. 661). Theory of Games. *Prerequisite: Math. 451 and 513.* 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.

615. Topics in Stochastic Processes. *Prerequisite: Ind. Eng. 516.* I or II. *(3).*
An intermediate level treatment of selected topics in renewal theory, fluctuation theory, Markov chains, and semi-Markov processes, with applications to queueing theory.

616. Queueing Theory II. *Prerequisite: Ind. Eng. 516.* I. *(3).*
Selected topics in queueing theory such as: priority schemes, departure processes, overflow processes, balking, reneging, batching.

633. Human Factors in Engineering Systems II. *Prerequisite: Ind. Eng. 533 or 534.* II. *(3).*
Topics in human performance, with emphasis on the development and application of concepts within specific operating environments. Topics such as definition of muscle fatigue and recovery functions, performance functions under image magnification, tool design criteria, and paced and unpaced decision functions.

640. Topics in Mathematical Modelling of Large Scale Systems. *Prerequisite: Ind. Eng. 540.* II. *(3).*
Advanced study in selected topics of Ind. Eng. 540.

641. Analysis of Inventory Systems II. *Prerequisite: Ind. Eng. 541. (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.

645. Topics in Reliability and Maintenance. *Prerequisite: Ind. Eng. 545.* II. *(3).*
Advanced study of selected topics from Ind. Eng. 545.

660. Special Topics in Decision Analysis. *Prerequisite: Ind. Eng. 560.* II. (every other year beginning with 1971.) *(3).*
Applications of statistical decision theory, with such methodologies involving on-line experimentation, large scale decision tree modification, and various heuristic and Markovian search concepts.

673. Administrative Information Processing Systems Analysis I. *Prerequisite: Ind. Eng. 573 and 575.* II. *(3).*
Theoretical analysis of administrative information processing systems. Extensions of language techniques for description of new hardware capabilities. The analysis of performance under different executive systems (e.g., real time, multi-processing, etc.) Theory of data management, data description languages, and storage management.

690. Graduate Study in Selected Problems I. *Prerequisite: permission of graduate committee.* I, II, III*a*, and III*b*. *(To be arranged).*

691. Special Topics in Industrial Engineering. *(To be arranged).*
Selected topics of current interest in industrial engineering.

711(Math. 760). Nonlinear Programming II. *Prerequisite: Ind. Eng. 611.* II. *(3).*
Generalization of convex functions, quasiconvexity and pseudoconvexity. Theorems for optimality in nonlinear programs involving generalized convex functions. Maximum principle. Duality in nonlinear programs. Rockafellar duality. Nonlinear programming algorithms. Use of computer codes.

715. Stochastic Service Systems. *Prerequisite: Ind. Eng. 615 or 616.* I or II. *(3).*
Topics in current research in stochastic service systems.

773. Administrative Information Processing Analysis II. *Prerequisite: Ind. Eng. 673.* I. *(1-3).*
Selected topics continuing the work of Ind. Eng. 673, with emphasis on operations research techniques. Students are expected to have completed a set of graduate courses in the stochastic processing and optimization area before entering this course.

790. Graduate Study in Selected Problems II. *Prerequisite: permission of graduate committee.* I, II, III, III*a* and III*b*. *(To be arranged).*

801(Hosp. Admin. 801). Research Seminar in Hospital and Medical Systems. *Prerequisite: graduate standing and permission of instructor.* I, II, III III*a* and III*b*. *(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. Outside speakers will present selected research topics. Readings, surveys, and development of research projects. May be elected more than once.

806. Seminar in Special Industrial Engineering Topics. *Prerequisite: Ind. Eng. 463.* II. *(To be arranged).*

810(Math. 861). Seminar in Mathematical Programming. *Prerequisite: permission of instructor.* I and II. *(1 or 2).*

815. Seminar in Stochastic Service Systems. *Prerequisite: permission of instructor.* I and II. *(1-3).*
A working seminar for researchers in stochastic service systems.

836. Seminar in Human Performance. *Prerequisite: permission of instructor.* I and II. *(To be arranged).*
Case studies of techniques used in human performance field. Reading and research in the application of human abilities to man-machine systems.

843. Seminar in Operations Research. I. *(1 or 2).*

844. Seminar in Operations Research. II. *(1 or 2).*

845. Seminar in Operations Research. III. *(1 or 2).*

873. Seminar in Administrative Information Processing Systems. *Prerequisite: Ind. Eng. 575.* II. *(1-3).*
Recent developments, case studies and individuals or group development projects in administrative information processing systems.

878. Seminar in Computer Graphics. *Prerequisite: Ind. Eng. 578.* I. *(1-3).*
Selected lectures and readings on recent developments in computer graphics.

906. Master's Thesis Project. *Prerequisite: permission of department.* I, II, III, III*a* and III*b*. *(6 maximum total—may be spread over several terms).*

916. Professional Thesis Project. *Prerequisite: permission of department.* I, II, III, III*a* and III*b*. *(To be arranged).*

990. Research in Industrial Engineering. *Prerequisite: permission of department.* I, II, III, III*a* and III*b*. *(To be arranged).*

992. Ph.D. Thesis Project. *Prerequisite: permission of department.* I, II, III, III*a* and III*b*. *(To be arranged).*

Materials and Metallurgical Engineering

Department Office: 2028 East Engineering
See page 112 for statement on Course Equivalence.

155(Eng. 155). Materials and Civilization. *Prerequisite: Chem. 103.* II. *(2). Not open to students having had Mat.-Met. Eng. 250.*
The history of materials of industry and their impacts on civilization—past, present, and future. The nature of the technological advances that affect social changes.

230(Chem. Eng. 230). Thermodynamics I. *Prerequisite: Chem. 103 or 104; must be accompanied by Mat.-Met. Eng. 231 (Chem. Eng. 231). (3).*
An introduction to applications of the first and second laws of thermodynamics. Material and energy balances, the equilibrium concept. Properties of fluids and solids. Engineering systems.

231(Chem. Eng. 231). Chemical Engineering Laboratory. *Prerequisite: must accompany Mat.-Met. Eng. 230 (Chem. Eng. 230). (1).*
Quantitative experiments involving the first law of thermodynamics and thermodynamic properties.

250. Principles of Engineering Materials. *Prerequisite: Chem. 103 or 104; preceded or accompanied by Physics 240. (3).*
An introductory course in the science of engineering materials. The engineering properties (mechanical, thermal, and electrical) of metals, polymers, and ceramics are correlated with: (1) their internal structures (atomic, molecular, crystalline, micro-, and macro-) and (2) service conditions (mechanical, thermal, chemical, electrical, magnetic, and radiative). Two lectures and two recitations.

310. Properties of Biomaterials. *Prerequisite: Mat.-Met. Eng. 250. (2).*
Properties (1) of prosthetic materials, (2) of simple biological materials such as bone, collagen, cellulose, and (3) of natural raw materials such as wood and fibers. Reactions between these materials and their environments.

351. Structure and Properties of Materials. *Prerequisite: Mat.-Met. Eng. 250. (4).*
The basic materials operations such as solidification, sintering, deformation, and heat treating are studied, with emphasis on laboratory methods used for analyzing the accompanying structure and property changes.

371. Physical Metallurgy I. *Prerequisite: Mat.-Met. Eng. 351. (3).*
Structure and properties of commercial metals and alloys as determined by composition and thermal and mechanical treatments. Lectures, recitation and laboratory.

444(Chem. Eng. 444). Properties of Gases, Liquids, Solids, and Surfaces. *Prerequisite: Chem. 469 and Chem. Eng. 330. (3).*
A study of chemical and phase equilibria involving the various states of matter. Applications of phase rule to multicomponent and mixed-state systems. Kinetics of state and phase changes. Structure and properties of gases, liquids, solids, and surfaces. Prediction and correlation of physical, chemical, and transport properties of various states and aggregates.

450. Physical Ceramics I. *Prerequisite: Mat.-Met. Eng. 250 and Chem. Eng. 330 or Mech. Eng. 335. (4).*
The nature, properties, processing, and applications of ceramic materials.

451(Chem. Eng. 451). Introduction to High Polymers. *Prerequisite: junior standing in engineering or science. (4).*
Preparation, properties, and utilization of polymeric materials. Lectures, recitation, and laboratory.

455. Theory of Solids. *Prerequisite: Mat.-Met. Eng. 371. (3).*
Dislocation theory, electron theory of metals, semiconduction, dielectrics, optical behavior, and magnetism.

472. X-ray Studies of Engineering Materials. *Prerequisite: Mat.-Met. Eng. 250. (3).*
Generation and properties of x-rays. Radiographic methods. Crystal geometry, stereographic projections. The diffraction of x-rays by crystals. Basic diffraction methods and their use in determining crystal size, shape, perfection and orientation. Identification of crystalline phases, measurement of lattice parameters and internal stress. Survey of crystal structure determination and chemical analysis by fluorescence and absorption spectroscopy. Lectures, recitation, and laboratory.

475. Fundamentals of Metal Casting. *Prerequisite: Mat.-Met. Eng. 351 or Mech. Eng. 251. (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 on solidification rates, fluidity of liquid metal, physics of mold design, slag-metal-gas equilibria, and an individually selected short research problem.

486(Chem. Eng. 486). Engineering Materials in Design. *Prerequisite: senior standing. (3).*
The study of the selection and specification of engineering materials for use in the chemical industry. Metals, ceramics, polymers, non-metals, coatings.

489. Metallurgical Process Design. *Prerequisite: Chem. 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(Chem. Eng. 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.

511(Chem. Eng. 511). Polymerization Reactions. *Prerequisite: a course in physical chemistry and a course in organic chemistry. (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.

512. Physical Polymers. *Prerequisite: senior or graduate standing in engineering or physical science. (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.

520. Physical Metallurgy II and Physical Ceramics II. *Prerequisite: Mat.-Met. Eng. 371 or Mat.-Met. Eng. 450. (3).*
Structural aspects of crystalline materials; crystal symmetry, angular relationships, topology of grains and phases; surfaces and surface phenomena; nucleation and growth theories; recrystallization and grain growth.

523(Mech. Eng. 552). Metal-Forming Plasticity. *Prerequisite: Mat.-Met. Eng. 371 or Mech. Eng. 450. (3).*
Elastic and plastic stress-strain relations; yield criteria and flow rules; analyses of various plastic forming operations including slip-line field and upper bound theories. Effects of work hardening and friction, temperature, strain rate and anisotropy.

532. Thermodynamics of Systems with Solids. *Prerequisite: Mat.-Met. Eng. 371 or 450, and a course in thermodynamics. (3).*
Laws of thermodynamics applied to metals and other inorganic materials.

550. Solid-State Kinetics. *Prerequisite: Chem. 468 or Chem. 265, and graduate standing. (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. Chemical Principles of Semiconductors. *Prerequisite: Mat.-Met. Eng. 250 and Elec. Eng. 314. (2).*
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.

552. Process Ceramics. *Prerequisite: Mat.-Met. Eng. 450 or Mat.-Met. Eng. 520. (3).*
Principles and practice of ceramic fabrication processes, microstructure development in ceramics, ceramic forming techniques, and sintering of compounds.

562. Ultrastructures I. *Prerequisite: Mat.-Met. Eng. 472. (4).*
A study of electron microscopy; electron, x-ray and neutron diffraction; optical and x-ray spectroscopy; electron microprobe analysis; and other important methods for studying the submicroscopic structure of materials, together with related theoretical concepts such as the absorption, emission, and scattering of radiation, reciprocal lattice theory, and crystal defects.

573(Chem. Eng. 573). Corrosion of Metals and Alloys. *Prerequisite: Mat.-Met. Eng. 371 or Mat.-Met. Eng. 486. (3).*
Fundamentals involved in choosing a metal for use in a corroding medium.

574. Alloy Steels and High Temperature Alloys. *Prerequisite: Mat.-Met. Eng. 371 or Mat.-Met. Eng. 486. (4).*
Theory and practice of alloy additions to steel to develop enhanced properties. Fundamental principles determining the behavior of metals at high temperatures and the engineering practice of their use.

579. Nuclear Metallurgy. *Prerequisite: Mat.-Met. Eng. 250. (3).*
Process, mechanical, and physical metallurgy of metals used in nuclear reactors; uranium, plutonium, and thorium. Radiation damage to solids. Container materials, fuel element design and fabrication, moderator and control elements, liquid metals.

580. Materials and Metallurgy Design. *(2 or 4).*
First half-term: Design of metallurgical and materials processing systems, selection and utilization of alloys and other materials for engineering applications. Economic aspects of design, estimating procedures.
Second half term: Engineering design and economic evaluation of a specific process and/or materials application. Original and individual work and excellence of reporting are emphasized. Oral examination on final report.

581. Cast Metals in Engineering Design. *Prerequisite: Mat.-Met. Eng. 371 or Mat.-Met. Eng. 486. (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.

583. Applied Chemical Metallurgy. *Prerequisite: Mat.-Met. Eng. 450 or Mat.-Met. Eng. 489. (3).*
Metal-slag-refractory-gas reactions; deoxidation, analysis of melting processes (e.g., BOF), nonmetallic inclusions, scale formation.

590. Materials and Metallurgical Engineering Research Survey. *(1).*
Research activities and opportunities in the Materials and Metallurgical Engineering programs. Lectures by University of Michigan faculty and guest lecturers. Topics are drawn from current research interests of the faculty. Brief weekly reports.

620. Physical Metallurgy III. *Prerequisite: Mat.-Met. Eng. 520. (2).*
Diffusion, kinetics of diffusion controlled and martensitic phase transformations, ternary systems.

623. Crystal Plasticity. *Prerequisite: Mat.-Met. Eng. 523 (or Mech. Eng. 552). (2).*
Yielding and plastic flow of single crystals and polycrystalline aggregates by slip and twinning. Lattice rotation and formation of crystallographic texture. Anisotropy resulting from crystallographic texture.

632. Topics in Metallurgical Thermodynamics. *Prerequisite: Mat.-Met. Eng. 532. (3).*
Topics such as solution models, surface effects, thermodynamics of stressed solids, irreversible thermodynamics, thermochemistry of melting and refining, slag-metal reactions.

653. Physical Ceramics III. *Prerequisite: Mat.-Met. Eng. 450 or Mat.-Met. Eng. 520. (2).*
Structure and properties of nonmetallic compounds with special emphasis on topics such as brittle fracture, dielectric and optical behavior, oxide and sulfide semiconductors, magnetic compounds, and refractory properties.

662. Ultrastructures II. *Prerequisite: Mat.-Met. Eng. 562. (2).*
A study of defect structures, precipitation processes, phase transformations, amorphous structures, residual stresses, and other phenomena relating to the submicroscopic structures of materials with emphasis on results obtainable by electron microscopy and x-ray and electron diffraction techniques.

690. Research Problems in Materials and Metallurgy. *(To be arranged).*
Laboratory and conferences. 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 faculty. Any problem in the field of materials and metallurgy may be selected. The student writes a final report on his project.

693. Special Topics in Materials and Metallurgy. *(To be arranged).*

890. Seminar in Materials and Metallurgy. *(To be arranged).*
Selected seminar topics in physical metallurgy, mechanical metallurgy, chemical metallurgy, physical ceramics, process ceramics, physical polymers, polymerization reactions, or electronic materials.

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

*Mathematics**

Department Offices: 3217 Angell Hall and 347 West Engineering

Professor Nesbitt, Chairman; Professors Bartels, Brown, Brumfiel, Cesari, Coburn, Dolph, Duren, Ellis, Fischer, Galler, Gehring, Goodrich, Harary, Hay, Heins, Higman, P. S. Jones, Kaplan, Kazarinoff, Kister, Leisenring, LeVeque, Lewis, Lyndon, Mayerson, McLaughlin, Pearcy, Piranian, Raymond, Reade, Shapiro, Shields, Smoller, Titus, Ullman and Wendel; Associate Professors Dickson, Federbush, Goldberg, Hicks, D. A. Jones, Kincaid, Krause, Lee, Moler, Ramanujan, Rosen, Schwartz, Storer, B. A. Taylor, Wasserman, Winter and Woodroofe; Assistant Professors Alexander, Bloom, Burroughs, Ciment, Hinman, Holsztynski, Jaco, Kueker, Lininger, Little, Milne, Orlow, Pittenger, Rabindranathan, Razar, Richen and Shih; Hildebrandt Research Instructors Blass, Papas, M. E. Taylor and Weinberger.

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; curve sketching. *(No credit for engineering students).*

* 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.

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).*
Numbers and coordinate systems; trigonometric functions and their graphs; inverse functions; applications. *(No credit for engineering students).*

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, II, and III*b*. *(4).*
Functions and graphs; derivatives, differentiation of algebraic functions, applications; definite and indefinite integrals, applications to polynomial functions.

116. Analytic Geometry and Calculus II. *Prerequisite: Math. 115.* I, II and III*a*. *(3). (Ordinarily elected concurrently with Math. 117.)*
Differentiation and integration of trigonometric, logarithmic and exponential functions; techniques of integration; sequences and infinite series.

117. Elementary Linear Algebra. *Prerequisite: Math. 115.* I, II, and III*a* *(2). (Ordinarily elected concurrently with Math. 116.)*
Solutions of systems of linear equations; vector spaces; matrices; linear transformations.

185, 186. Analytic Geometry and Calculus I and II. *Prerequisite: permission of the Honors or the Unified Science counselor.* 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, 117, 215, and 350.

195, 196. Analytic Geometry and Calculus. *Prerequisite: permission of the Honors counselor.* 195, I; 196, II. *(4 each).*
For superior students having outstanding high school records in mathematics. The sequence Math. 195, 196, 295, 296, 495, 496 includes the content of Math. 115, 116, 117, 215, 216, 404, 451, 452, and 513, 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.

215. Analytic Geometry and Calculus III. *Prerequisite: Math. 116 and preceded by or concurrent with Math. 117. (4).*
Vector algebra; conic sections and quadric surfaces; vector calculus, multiple integrals; partial derivatives.

216. Introduction to Differential Equations. *Prerequisites: Math. 117, 214 or 215.* I, II. *(3).*
Solutions of first order equations, linear equations with constant coefficients, and linear systems; power series solutions; applications. Prospective mathematics majors should elect Math. 350 and 286 instead of 216.

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 programs for the computer. *(Not to be elected by engineering students who have completed Eng. 102, 110, or 120.)*

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. 216 with some deeper penetrations and some additional topics.

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 216, 404, 451, and 452 but there is a deeper penetration into many topics.

300(Elec. Eng. 300). Mathematical Methods in System Analysis. *Prerequisite: Math. 216.* I, II and III*b*. *(3).*
The elements of complex analysis; Fourier, Laplace and z transforms, with emphasis on their application to linear, differential and difference equations with constant coefficients.

305(Elec. Eng. 305). Mathematical Methods of Field Analysis. *Prerequisite: Math. 216.* I, II and III*b*. *(3).*
Vector differential and integral calculus. Line, surface and volume integrals. Fourier series and orthogonal functions. Solution of partial differential equations by separation of variables with emphasis on engineering applications (e.g. Laplace's equation, the wave equation).

315, 316. See Mathematics, page 27.

350. Introduction to Analysis. *Prerequisite: Math. 214 or 215.* I and II. *(3).*
Set theory and cardinal numbers, properties of the integers and real number system, topology of the reals, sequences, series, power series. Provides mathematics majors with a more rigorous introduction to the basic ideas required in subsequent concentration courses.

404. Differential Equations. *Prerequisite: Math. 216 or 286.* I and II. *(3).*
Systems approach to linear differential equations and physical applications. Simultaneous linear equations, solutions by matrices. Power series solutions. Numerical methods. Phase plane analysis of nonlinear differential equations.

412. First Course in Modern Algebra. *Prerequisite: Math. 350 or permission of instructor.* I, II, III*a* and III*b*. *(3).*
Fields and domains. Polynomials. Divisibility. Solution of polynomial equations. Symmetric functions. Determinants. Vector spaces.

417. Matrix Algebra I. *Prerequsite: three terms of college mathematics.* I, II, III*a* and III*b*. *(3).*
Algebra of matrices. Real vector spaces. Linear transformations. Determinants. Invariants and canonical forms. Elementary theory of similarity. Students intending to continue to research level should elect Math. 513.

418. Matrix Algebra I. *Prerequisite: Math. 417.* I and II. *(3).*
Similarity theory. Euclidean and unitary geometry. Applications to linear differential equations, least squares, and principal components. Doctoral students should elect Math. 514.

425(Statistics 425). Introduction to Probability. *Prerequisite: Math. 214 or 215.* I, II and III*b*. *(3).*
Sample spaces. Random variables, expectations. Independence, conditional probability, Bayes' theorem. Markov chains. Continuous and discrete distribution functions; various special distributions. Sequences of independent trials, random walks. DeMoivre-Laplace theorem, weak law of large numbers.

433. Introduction to Differential Geometry. *Prerequisite: Math. 450 or 451 or permission of instructor.* 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.

448. Operational Methods for Systems Analysis. *Prerequisite: Math. 450 or 451.* I, II, III*a* and III*b*. *(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. 216 or 286.* I, II, III*a* and III*b*. *(4).*
Topics in advanced calculus including vector analysis, improper integrals, line integrals, partial derivatives, directional derivatives, infinite series.

451. Advanced Calculus I. *Prerequisite: Math. 285 or 350 or equivalent. Intended for mathematics majors, other students desiring advanced calculus should elect Math. 450.* I, II, III*a*. *(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.

454. Fourier Series and Applications. *Prerequisite: Math. 216 or 286.* I, II, and III*a*. *(3).*†
Orthogonal functions. Fourier series, Bessel functions. Legendre polynomials and their applications to boundary value problems in mathematical physics.

471. Numerical Calculus. *Prerequisite: Math. 216 or 286 and some knowledge of computer programming.* I. *(3).*
Examples of basic mathematical methods used in computing. Polynomial interpolation. Numerical integration. Numerical solution of ordinary differential equations. Linear systems of equations. Monte Carlo techniques. Roundoff error. Students will use a digital computer to solve problems.

473(Com. Sci. 473). Introduction to Digital Computers. *Prerequisite: Math. 214 or 216 and Math. 273 or CCS 274 or equivalent.* I and II. *(3).*
Characteristics and logic of general purpose digital computers; introduction to logical design. The concept of algorithm, language, and symbol manipulation as applied to computer programming. Computational methods for linear systems, differential equations, etc. Laboratory work in programming the IBM 360/67 computer in several languages.

495. Analysis II. See listing for Math. 296.

496. Analysis III. See listing for Math. 296.

† Math. 454 carries 1 hour credit for students with credit for Math. 554.

502. Functional Analysis for Applications. *Prerequisite: Math. 417 or 513; Math. 451 or 594, or Math. 450 with permission of instructor. (3).*
Metric spaces, completion, contraction mappings and fixed points, survey of Lebesgue measure and integration, Banach and Hilbert spaces, function spaces, duality; other selected topics as time permits.

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.

514. Topics in Linear Algebra. *Prerequisite: Math. 513.* I and II. *(3).*
Advanced theory of vector spaces. Geometry of bilinear forms. Modules over principal ideal domains. Similarity theory. Multilinear algebra.

525, 526(Statistics 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.

540. Theory of the Potential Function. *Prerequisite: Math. 450 or 451.* II. *(3).*
Newtonian attraction, Newtonian and logarithmic potentials, equations of Laplace and Poisson, harmonic functions, principle of Dirichlet and Neumann, and Green's functions.

543. 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.

554. Advanced Mathematics for Engineers II. *Prerequisite: Math. 450.* I and II. *(4). Not open to students with credit for Math. 454 or 555.*
Topics in advanced calculus including functions of a complex variable, Fourier series and orthogonal functions, applications to boundary value problems.

555. Introduction to Functions of a Complex Variable with Applications. *Prerequisite: Math. 450 or 451.* I and II. *(3).*†
Complex numbers; limit, continuity, derivative; conformal representation; integration; Cauchy theorems; power series; singularities; applications to engineering and mathematical physics.

556. Methods of Applied Mathematics I. *Prerequisite: Math. 555 or 554. (3).*
A study of some of the differential equations of mathematical physics and methods for their solution. Separation of variables for the heat, wave, Laplace's and Schroedinger's equations; special functions, their integral representations and asymptotic properties; eigenvalues as solutions of variational problems.

557. Methods of Applied Mathematics II. *Prerequisite: Math. 556. (3).*
Continuation of Math. 556. Elementary distributions; Green's functions and integral solutions for nonhomogeneous problems; Fourier and Hankel transforms; Fredholm alternative and elementary methods of solution of integral equations; additional topics as time permits.

* Math. 525 carries 1 hour credit for students with credit for Math. 425.
† Math. 555 carries 1 hour credit for students with credit for Math. 554.

588. Theory of Initial Value Problems. *Prerequisite: Advanced calculus and some linear algebra, or permission of instructor.* I. *(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. Theory of Boundary Value Problems. *Prerequisite: Math. 555 and 558, or permission of instructor.* 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.

561(Bus. Ad. Stat. 518; IE 510). Linear Programming I. *Prerequisite: Math. 417. (3).*
Formulation of problems from industry, government, etc. as linear programs. The simplex algorithm. Duality, complementary slackness theorems and economic interpretation of dual variables. Reversed simplex method. Parametric programming, sensitivity analysis. Flow in networks. Transportation problem. Use of computer codes like MSUB.

562(Ind. Eng. 511). Mathematical Programming with Application. *Prerequisite: Math. 561. (3).*
Convex quadratic programming, bimatrix games, and complementary pivot theory. Lagrange multiplier technique. Kuhn-Tucker equations. Combinatorial and integer programming, shortest routes on networks, project networks, critical path problems. Dynamic programming, Markovian programming. Emphasis on presentation of methods with applications.

565. Theory of Graphs. *Prerequisite: Math. 214 or 215. (3).*
Historical introduction, basic concepts of graphs and directed graphs, cutpoints, bridges and blocks trees, connectivity, graphical partition, Eulerian graphs, factorization, coverings, topological graph theory, coloring problems. Applications.

566. Combinatorial Theory. *Prerequisite: Math. 216 or 286 or permission of instructor. (3).*
Permutations, combinations, generating functions, and recurrence relations. The existence and enumeration of finite, discrete configurations. Systems of representatives, Ramsey's Theorem, and extremal problems. Construction of combinatorial designs.

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.* I and 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.

581. Introduction to Mathematical Logic. *Prerequisite: Math. 214 or 350 or permission of instructor.* I. *(3).*
Formal languages and their interpretations. Propositional logic, predicate logic, and applications to problems of consistency, completeness, and decidability of mathematical theories.

594. Intermediate Analysis for Engineers. *Prerequisite: Math. 450.* I. *(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.

601. Real Analysis I. *Prerequisite: Math. 451 and 513.* I and II. *(3).*
Lebesgue measure and integration on the line; convergence theorems, functions of bounded variation, absolute continuity, differentiation theory in one and several variables; general measure spaces; product spaces, Fubini's theorem; Radon-Nikodym theorem.

602. Real Analysis II. *Prerequisite: Math. 590 and 601.* II. *(3).*
Introduction to functional analysis; metric spaces, completion, Banach spaces, Hilbert spaces, L_p spaces; linear functionals, dual spaces; Riesz representation theorems; principle of uniform boundedness, closed graph theorem, Hahn-Banach theorem, Baire category theorem; applications to classical analysis.

603. Complex Analysis I. *Prerequisite: Math. 451.* I and II. *(3).*
Elementary functions of a complex variable; linear fractional transformations; complex derivatives; conformality; Cauchy's theorem, Cauchy's integral formula and consequences; Taylor and Laurent series; analytic continuation.

604. Complex Analysis II. *Prerequisite: Math. 603.* II. *(3).*
Selected topics such as normal families, Riemann mapping theorem, conformal mapping of multiply connected domains; elliptic functions; entire and meromorphic functions, Picard's theorem, value distribution theory; Phragmén-Lindelöf theorems; harmonic functions, Dirichlet problem; schlicht functions.

607. Theory of Distributions. *Prerequisite: Math. 601.* I. *(3).*
Theory of distributions. Sobolev spaces. Fundamental solution of partial differential equations. Boundary value problems. Solutions of problems of optimization with partial differential equations as side conditions. Theorems of regularity. Characterization of singularities.

625.(Statistics 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.(Statistics 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.

642. Theory of Linear Integral Equations. *Prerequisite: Math. 451, 555, an advanced course in differential equations or permission of instructor.* I. *(3).*
Fredholm theory, compact integral equations, singular integral equations of the Cauchy and convolution type.

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.

651. Foundations of Applied Mathematics I. *Prerequisite: Math. 451, 555, and one other 500 level course in analysis or differential equations or consent of the instructor.* I. *(3).*
The regular Sturm-Liouville theory for ordinary and partial differential equations including the rudiments of spectral theory and operator theory.

652. Foundations of Applied Mathematics II. *Prerequisite: Math. 651 or consent of instructor.* II. *(3).*
A continuation of Math. 651. Spectral theory of self-adjoint operators and an introduction to the singular Sturm-Liouville theory.

655. Advanced Theory of Integral Equations. *Prerequisite: Math. 651 or permission of instructor. (3).*
Modern developments in the theory of integral equations.

656. Advanced Partial Differential Equations. *Prerequisite: 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. Qualitative study of flows and vector fields in the plane and on 2-manifolds. Periodic solutions, Hamiltonian systems, stability.

660.(Ind. Eng. 610). Linear Programming II. *Prerequisite: Math. 561.* II. *(3).*
For description, see Ind. Eng. 610.

661.(Ind. Eng. 613). Theory of Games. *Prerequisite: Math. 451 and 513.* I. *(3).*
For description, see Ind. Eng. 613.

663.(Ind. Eng. 611). Nonlinear Programming I. *Prerequisite: Math. 561, 594 or 490.* I. *(3).*
For description, see Ind. Eng. 611.

668. Topics in Graph Theory. *Prerequisite: Math. 565 or 566, or permission of instructor. (3).*
Selected subjects chosen usually from the areas of graphs and matrices, graphs and their groups, topological graph theory, and extremal problems.

669. Topics in Combinatorial Theory. *Prerequisite: Math. 565 or 566, or permission of instructor. (3).*
Selected topics from the foundations of combinatorics, including the analysis of general partially ordered sets, combinatorial designs in loops and structures in abstract systems, enumeration under group action, combinatorial aspects of finite simple groups.

707. Calculus of Variations. *Prerequisite: Math. 601 or permission of instructor.* I. *(3).*
The study of curves which minimize a definite integral. Relative and absolute minima and maxima. Necessary conditions. Sufficient conditions. Lower semicontinuity of functionals. Existence theorems. Direct methods. Problems of Lagrange, Mayer, and Bolza. Problems of optimal control. Trajectories. Control functions. Pontryagin necessary conditions. Filippov's selection theorem. Closure theorems of trajectories. Existence theorems. Applications.

708. Topics in the Calculus of Variations. *Prerequisite: Math. 601 or permission of instructor. Natural continuation of Math. 707, but can be taken independently.* II. *(3).*
Free problems of the calculus of variations for multiple integrals. The Dirichlet problem. Euler partial differential equations. Other necessary conditions. Sobolev

spaces. Lagrange problems and problems of optimal controls for multiple integrals with partial differential equations, boundary conditions, and constraints. Existence theorems for Lagrange problems and for free problems based on convexity, lower closure, lower semicontinuity. Problems of optimal control with elliptic, hyperbolic, and parabolic equations. Necessary conditions.

760. (Ind. Eng. 711) Nonlinear Programming II. *Prerequisite: Math. 663.*
For description, see Ind. Eng. 711.

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
See Page 112 for statement on Course Equivalence.

251. Control of Mechanical Properties of Solids. *Prerequisite: Mat.-Met. Eng. 250 and preceded or accompanied by Eng. Mech. 211.* 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: Mat.-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. Fluid Mechanics. *Prerequisite: Mech. Eng. 335 and Eng. Mech. 340.* I and II. *(4).*
Control volume analysis; continuity, momentum, angular momentum, and energy equations. Dimensional analysis and similitude. Introduction to differential analysis; kinematics; fluid statics; inviscid flow; potential flow; simple viscous incompressible flow; lift and drag. Steady one-dimensional compressible flow. Applications to fluid machinery and systems. Three lectures and one three-hour laboratory.

331. Classical and Statistical Thermodynamics. *Prerequisite: Chem. 103 or 104, 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. Four lectures.

335. Thermodynamics I. *Prerequisite: Chem. 103 or 104, and Math. 116.* I and II. *(3).*
Basic course in engineering thermodynamics. First law, second law, system and control volume analyses; properties and behavior of pure substances, ideal gases and mixtures. Three lectures.

336. Thermodynamics II. *Prerequisite: Mech. Eng. 335, Eng. 102 and Math. 215.* 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. 340.* I and II. *(4).*
An introduction to the analysis of simple dynamic systems by applying instrumentation, the analog computer and vibration theory to practical mechanical systems. Three one-hour lectures and one three-hour laboratory.

362. Mechanical Design I. *Prerequisite: Eng. Mech. 211 and Mech Eng. 251.* 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.

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.

424. Fundamentals of Modern Acoustics. *Prerequisite: Mech. Eng. 324 or Eng. Mech. 324.* II. *(3).*
Plane waves and acoustic fields of point sources. Method of characteristics and x-t diagrams. Transmission and radiation phenomena: two- and three-interface problems, sound transmission through walls. Random processes, correlation and power spectral density relations. Similarity methods. Wavy wall and other special acoustical problems; concepts of noise and vibration control in mechanical system design.

432. Combustion. *Prerequisite: Mech. Eng. 336, preceded or accompanied by Mech. Eng. 471.* 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.* 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.* 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.

441. Kinematic Analysis and Synthesis. *Prerequisite: Eng. Mech. 340 and Eng. 102.* II. *(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. 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.

451. Nondestructive Evaluation of Materials. *Prerequisite: Mat.-Met. Eng. 250.* I. *(3).*
Theory and practice of the nondestructive evaluation of the integrity of materials by the use of electromagnetic, ultrasonic, sonic, x-ray, and holographic techniques. Two one hour lectures and one three hour laboratory.

460. Mechanical Design II. *Prerequisite: Mech. Eng. 362, 381, and 471 which may be taken concurrently.* I, II, and III*a*. *(3).*
A mechanical engineering design project by which the student is exposed to the design process from concept through analysis to layout and report. Projects are proposed from the different areas of study within mechanical engineering and reflect the expertise of instructing faculty. Two, four-hour design periods.

461. Automatic Control. *Prerequisite: Mech. Eng. 340.* I and II. *(4).*
Linear feed-back control theory with emphasis on mechanical systems; transient and frequency response; stability; system performance; control modes; compensation methods; analysis of hydraulic, pneumatic, inertial components and systems. Three one hour lectures and one three hour laboratory.

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.

471. Transport of Heat and Mass. *Prerequisite: Mech. Eng. 335 and 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 or 252.* I and II. *(4).*
Application of engineering fundamental 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. 471). Numerical Control of Manufacturing Processes. *Prerequisite: Mech. Eng. 381 or Ind. Eng. 373 and Mech. Eng. 252.* I and 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. 362.* I and II. *(3).*
Correlation between functional specifications and process capabilities. Study of tolerance 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 at the end of the term. 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. *Perequisite: Mech. Eng. 362.* II. *(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.* 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.* 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.

537. Power Generation Systems. *Prerequisite: Mech. Eng. 471 and Nuc. Eng. 400 or 430.* I. *(3).*
Analysis of nuclear and fossil-fuel energy conversion power plants. Course emphasis on the interplay of design constraints, including thermodynamics, fluid and heat transport, stresses, nucleonics and economics. Design problems concerning the major components of power generation systems.

538(Chem. Eng. 549). Air Pollution Control. *Prerequisite: Mech. Eng. 471 or Chem. Eng. 341 or 342.* II. *(3).*
Principles of control techniques, fundamentals or process modification to reduce pollution, and legal requirements. Includes furnace and internal combustion sources, particulate control devices, and vapor control systems.

539. Cryogenics and Refrigeration. *Prerequisite: Mech. Eng. 336 and preceded or accompanied by Mech. Eng. 471.* II. *(3).*
Theoretical and design aspects of producing temperatures below ambient. Vapor compression systems; absorption systems; liquefaction and separation of air; liquefaction and properties of cryogenic fluids; insulation problems; and unique phenomena at extremely low temperatures.

540. Dynamics of Mechanical Systems. *Prerequisite: Eng. Mech. 340.* I, II, and III*a*. *(3).*
Transient and steady-state response of mechanical vibration systems. Transform and matrix methods applied to rectilinear and torsional systems having multiple degrees of freedom. Impact loading. Balancing and vibration isolation. Lagrange representation of non-linear dynamics of machinery. Solution by analog and digital computer.

546(Bioeng. 546). Biomechanics I. *Prerequisite: Mech. Eng. 340 or Mech. Eng. 540.* I. *(3).*
Statics, kinematics, and dynamics of body motions; study of body motion response to various dynamic load inputs utilizing lumped parameter methods; properties of biological materials; tolerance of man to adverse environments including impact, vibration, weightlessness; appropriate physiological failure criteria.

549(Aero. Eng. 549) (Eng. Mech. 549). Random Vibrations of Mechanical Systems. *Prerequisite: Eng. Mech. 340 or Eng. Mech. 343.* II. *(3).*
Random mechanical inputs: wind buffeting; earthquakes; surface irregularities. Engineering applications include response of a linear spring-mass system and an elastic

beam to single and multiple random loading. Failure theories. Necessary concepts such as ensemble averages, correlation functions, stationary and ergodic random processes, power spectra, are developed heuristically.

550. Dislocations and Strength. *Prerequisite: Mech. Eng. 450.* 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.* 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(Mat.-Met. Eng. 523). Metal-forming Plasticity. *Prerequisite: Mech. Eng. 450 or Mat.-Met. Eng. 371. (3).*
Elastic and plastic stress-strain relations; yield criteria and flow rules; analyses of various plastic forming operations including slip-line field and upper bound theories. Effects of work hardening and friction, temperature, strain rate and anisotrophy.

553. Friction and Wear. *Prerequisite: Mech. Eng. 450 or Mat.-Met. Eng. 351.* 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. 362.* 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.

560. Decision Making for Creative Design. *Prerequisite: Mech. Eng. 460.* II. *(3).*
Prepared engineering case histories are used to gain student involvement in study and discussion of the decision making aspects of conceptual design. Discussion topics include problem recognition and definition, identification of alternate solutions, prediction techniques and value criteria. Other considerations are invention, product development, costs and investment economics, safety, reliability, human factors and marketing.

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.* II. *(3).*
Automatic controls; fluid metering; measurements of temperature, humidity, pressure, displacement, strain, speed, sound, etc.

564. Computer Aided Design Methods. *Prerequisite: Math. 473.* 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: multiprogramming, multi-processing and time-sharing systems.

567. Reliability Consideration in Design. *Prerequisite: Mech. Eng. 343 or 362.* 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.* 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.

569. Analysis of Mechanical Failures. *Prerequisite: Mech. Eng. 362.* II. *(3).*
Classification of failures in mechanical components. Basic causes. Criteria. Theories. Mechanisms. Crack propagation. Correlation of fractures with bending axial, and torsional loading. Overload and shock. Failures due to design, to material, and to manufacturing methods. Operational failures. Adhesion, abrasion, pitting, and spalling. Cavitation. Galvanic corrosion. Fretting. Stress corrosion cracking.

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.

574. Heat Transfer and Two-Phase Flow. *Prerequisite: Mech. Eng. 471.* II. *(3).*
Mechanisms of liquid-vapor phase changes; nucleation phenomena; bubble dynamics; cavitation; pool and flow boiling heat transfer; condensation heat transfer. Hydrodynamics of two-phase flow.

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.* 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. Automative 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.

635. Thermodynamics IV. *Prerequisite: Mech. Eng. 535.* II. *(3).*
Discussion of thermodynamic systems including surface phenomena, external fields, and relativistic effects. Study of complex equilibrium calculations including effect of heterogeneous reactions and real substance behavior. Introduction to the thermodynamics of irreversible processes with applications to heat and mass transfer, relaxation phenomena and chemical reactions.

640. Mechanical Vibrations. *Prerequisite: Mech. Eng. 540.* I. *(3).*
Vibration of multifreedom systems with linear and nonlinear damping due to periodic and non-periodic loading. Normal modes. Exact and approximate analysis of continuous systems. Analysis of noise and random vibration. Utilization of generalized computer programs for vibration analysis. Application to systems common to mechanical engineering.

642. Simulation of Mechanical Systems. *Prerequisite: Mech. Eng. 540.* I. *(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.* 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.* II. *(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; electro-magnetic 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: graduate standing and permission of instructor.* I or II. *(To be arranged).*
Reports and discussions on library study and laboratory research in selected 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: 4072 East Engineering
See Page 112 for statement on Course Equivalence.

202. Weather and Climate. I and II. *(3). Not open to meteorology majors.*
Elementary description of the atmosphere: its motion systems, thermal characteristics, 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 140.* 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. Thermodynamics of the Atmosphere and Oceans. *Prerequisite: Physics 240 and preceded or accompanied by Math. 316.* I. *(3).*
Physical principles of thermodynamics with emphasis on oceanic and atmospheric applications. Topics include: equations of state; first and second laws of thermodynamics, adiabatic processes; energy conservation laws, internal and potential energies and energy transformation; thermodynamics of water phases; heat transfer, molecular and eddy diffusion of heat; thermodynamic diagrams; topics from statistical thermodynamics.

332. Radiative Processes in the Atmosphere. *Prerequisite: Meteor.-Ocean. 305, Physics 240, Math. 215.* II. *(3).*
The nature of radiation, solar and terrestrial radiation, scattering, atmospheric visibility, satellite measurements of solar and terrestrial radiation.

333. Physical Oceanography. *Prerequisite: Meteor-Ocean. 305.* I. *(3).*
Physical conditions and physical processes of the oceans; integration of observations into comprehensive descriptions of ocean phenomena, and theoretical explanations. Emphasis on currents, tides, waves, and turbulent phenomena.

350(Nav. Arch. 350). Ocean Engineering I. *Prerequisite: Civ. Eng. 324(Eng. Mech. 324).* II. *(3).*
A descriptive course to introduce students to the evolving field of ocean engineering by means of lectures on relevant aspects of oceanography and engineering followed by case studies of ocean engineering systems. Pertinent physical, chemical, biological, and geological properties of the oceans; types of vehicles and structures in use in and on the oceans and their performance capabilities and limitations; diving systems, mooring and other selected topics.

351. Geophysical Fluid Dynamics. *Prerequisite: Math. 316, Physics 240, Chem. 265.* I. *(3).*
Dynamics and thermodynamics of the oceans and atmosphere. Equations of motion for a rotating system; thermodynamics; kinematic principles; vorticity; geostrophic flow.

360. Oceanographic Field Methods. *Prerequisite: Meteor.-Ocean. 307.* IIIa. *(8).*
Integrated lecture, laboratory and field program including: shipboard handling of apparatus; methods of navigation; bathymetry; geological, chemical, physical, and biological oceanographic sampling techniques. Methods used in wave measurement. Marine meteorological observations.

The course to be conducted at the Biological Station, Pellston, Michigan. Observational exercises held on Douglas Lake and aboard research vessel on Lake Huron.

407. Methods in Climatology. *Prerequisite: Stat. 410; 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 cleaning 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. Geology of the Great Lakes. *Prerequisite: permission of the instructor.* I. *(2).*
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 240 or Math. 215.* 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.

441. Oceanography. *Prerequisite: college credits in chemistry, physics, biology, and geology.* III. *(4).*
An introduction to oceanography for graduate and advanced undergraduate students who have had training in basic sciences. The course will present basic physical, chemical, geological, and biological concepts and principles of oceanography in a combination of classroom lectures, laboratory work, and practical experience aboard a research vessel.

442. Oceanic Dynamics I. *Prerequisite: Meteor.-Ocean. 351.* II. *(4).*
Wave motions; group velocity and dispersion. Gravity waves, wave statistics and predictional methods; long period waves; the tides. Steady state circulation, including theories of boundary currents and the thermocline.

449. Marine Geology. *Prerequisite: permission of instructor.*
Topography, geomorphology, sediments, processes and environments of the oceans; characteristics of oceanic segments of the earth's crust; theories of structural development.

450(Nav. Arch. 450). Ocean Engineering II. *Prerequisite: Civ. Eng. 324(Eng. Mech. 324).* I. *(3).*
Engineering analyses of work systems for operation in and on the ocean, primarily submersibles and offshore drilling platforms. Selected aspects of physical oceanography, underwater acoustics, and instrumentation.

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.* 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.* II. *(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). Introduction to Aeronomy. *Prerequisite: senior or graduate standing in a physical science or engineering.* I. *(3).*
An introduction to physical processes in the upper atmosphere; density, temperature, composition, and winds; atmospheric radiation transfer processes and heat balance; the ionosphere; rocket and satellite measurement techniques.

469(Nav. Arch. 469). Underwater Operations. *Prerequisite: permission of instructor.* II. *(3).*
Survey of manned undersea activities in oceanography and ocean engineering. The tools of underwater operations: decompression chambers, habitats, submarines, diving apparatus; pertinent design criteria and applications as based on human hyperbaric physiology and performance. Topics in research diving for engineering and oceanographic studies.

478. Marine Chemistry. *Prerequisite: Chem. 265.* I. *(3).*
Chemical equilibria and properties of marine waters which affect composition, variations in pH, and formation of sediments. Stable and radioactive isotope abundances in sea water. Factors which affect rates of organic and inorganic reactions and gas transfer processes in the sea. Chemical nutrient balance in the marine environment.

479. Atmospheric Chemistry. *Prerequisite: Chem. 265.* II. *(3).*
Physical chemistry of water vapor-liquid equilibria in the atmosphere, curvature effects in small droplets, and stable isotope fractionation. Origin and reactions of major and trace gases in the troposphere. Properties of natural and pollution aerosols, and the chemistry of precipitation. Altitude variations in the chemical composition of the atmosphere.

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.

499. Directed Study for Undergraduate Students. *Prerequisite: permission of instructor.* I, II, III, III*a* and III*b*. *(To be arranged).*
Directed reading, research, or special study for advanced undergraduate students.

522. Micrometeorology II. *Prerequisite: Math. 316, Physics 240.* 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.

526(Eng. Mech. 526). Dynamics of the Oceans and Atmosphere. *Prerequisite: preceded or accompanied by Eng. Mech. 422.* II. *(3).*
Dynamics of rotating stratified flow, the β-plane approximation; wave motions; geostrophic adjustment, Gulf Stream theory, and other topics of interest in geophysical fluid mechanics.

531. Marine Ecology. *Prerequisite: graduate standing in a science.* II. *(4).*
Interactions of biological, chemical, geological, and physical factors in the marine environment. Designed to show and analyze the complex interrelationships occuring in the aquatic environment, especially as these are reflected by the biological economy.

532. Radiative Transfer—Thermal Processes. *Prerequisite: Chem. 580, and Aero. Eng. 532 or Elec. Eng. 580.* II. *(3).*
The fundamental principles of molecular radiative transfer applicable to planetary atmospheres; macroscopic and microscopic forms of the transfer equation for both grey and non-grey cases; line broadening mechanisms; band models; nonlocal thermodynamic equilibrium source functions for a two-level molecule and for multilevel systems.

533. Radiative Transfer—Scattering. *Prerequisite: Meteor.-Ocean. 332, and Physics 405 or Elec. Eng. 420.* II. *(3).*
The basic theory of atmospheric scattering. Single scattering, Rayleigh scattering, introduction to the Mie theory; multiple scattering in planetary atmospheres, scattering by clouds, Monte Carlo techniques; scattering and extinction experiments as a tool for atmospheric measurements.

542. Oceanic Dynamics II. *Prerequisite: Meteor.-Ocean. 442.* I. *(3).*
Circulation in the world ocean; interaction of the oceans and atmosphere; boundary currents, the thermocline, equatorial currents; the thermohaline circulation.

550(Nav. Arch. 550). Ocean Engineering III. *Prerequisite: Nav. Arch. 450 (Meteor.-Ocean. 450).* I and II. *(To be arranged).*
Advanced reading and problem resolution in specific areas of ocean engineering, usually followed by presentation of a seminar or preparation of a substantial term paper.

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.

560. Oceanography Field Practicum. *Prerequisite: Meteor.-Ocean. 333 and graduate standing.* III*a*. *(8).*
Design and implementation of oceanographic observational programs; marine data gathering capabilities: research vessels, buoys, etc.; shipboard data processing. Current techniques in physical, chemical, geological and biological oceanography, marine geophysics and marine meteorology. Course to be conducted at and in conjunction with a marine laboratory.

564. The Stratosphere and Mesosphere. *Prerequisite: Meteor.-Ocean. 351.* 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. Planetary Atmospheres. *Prerequisite: Meteor.-Ocean. 351, Physics 453.* 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; aspects of the solar atmosphere; theoretical and empirical results, including planetary observation by space probes.

566. Design and Response of Meteorological Instruments. *Prerequisite: Meteor.-Ocean. 462.* 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 inputs. 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.

578(E.H. 578). Air Pollution Chemistry. *Prerequisite: Chem. 265.* I. *(3).*
Chemical properties of gaseous and particulate inorganic and organic air pollutants. Transfer processes which affect interchange of pollutants between the atmosphere and surface water. Analytical processes for the determination of air pollutants. Systems for the analysis of trace metals and organics. Theory of interaction of light and air pollutant molecules for continuous monitoring.

579. Atmospheric and Marine Radioactivity. *Prerequisite: Chem. 265.* II. *(3).*
Properties of radioactive materials in the atmosphere and oceans. Formation of natural atmospheric radioactivity by cosmic radiation and outgassing of the earth's crust. Contamination of the atmosphere and oceans by nuclear wastes. Use of natural and artificial radioactivity in atmospheric and oceanic circulation studies and in geochronology of marine sediments.

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-Fluid Problems. *Prerequisite: Meteor.-Ocean. 442 or 451, and Eng. 102 and Math. 450.* II. *(3-4).*
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: Stat. 410.* 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: Stat. 411 and Meteor.-Ocean. 351.* I. *(3).*
Statistical characteristics of continuous random functions and fields; microstructure and macrostructure of atmospheric turbulence; concentration distribution of conservative, passive additives; diffusion models.

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.

991. Oceanographic Research. *Prerequisite: permission of graduate advisor.* I and II. *(To be arranged).*
Assigned work in oceanographic research; may include field measurements, analysis of data, development in physical, chemical, geological, or biological oceanography.

994. Doctoral Thesis. I and II. *(To be arranged).*

Naval Architecture and Marine Engineering

Department Office: 445 West Engineering
See Page 112 for statement on Course Equivalence.

200. Introduction to Naval Architecture. *Prerequisite: Eng. 101.* I and II. *(4).*
Types of ships, their nomenclature, materials and methods of construction. Drawings of hull lines and structure. Calculations of buoyancy, displacement, wetted surface. Use of hydrostatic curves, trim, stability, launching, watertight subdivision.

300. Computer Techniques in Naval Architecture. *Prerequisite: Eng. 102, Nav. Arch. 200.* I and II. *(2).*
Programming of hydrostatic curves; other problems for digital and analog computers.

310. Structural Design I. *Prerequisite: Eng. Mech. 211.* I, II, and III*a*. *(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 Engineering I. *Prerequisite: Mech. Eng. 335 or 331.* II. *(4).*
Principles of propulsion and of propulsion machinery. Analysis of steam power cycles, and design problems relating to turbines, boilers, and heat exchangers.

331. Marine Engineering II. *Prerequisite: Nav. Arch. 330, Eng. Mech. 324.* I. *(3).*
Analysis of diesel and gas turbine engines as propulsion machines. Piping, pumps, and electrical systems for ship application.

350(Meteor.-Ocean. 350). Ocean Engineering I. *Prerequisite: Civ. Eng. 324(Eng. Mech. 324).* II. *(3).*
A descriptive course to introduce students to the evolving field of ocean engineering by means of lectures on relevant aspects of oceanography and engineering followed by case studies of ocean engineering systems. Pertinent physical, chemical, biological, and geological properties of the oceans; types of vehicles and structures in use in and on. the oceans and their performance capabilities and limitations; diving systems, mooring 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. (2).*
Design of motorboats, hydrofoils, and other small craft.

402. Small Commercial Vessel Design. *Prerequisite: preceded or accompanied by Nav. Arch. 420. (2).*
Design of small commercial craft such as fishing boats, tugs, towboats, barges, and coasters.

403. Sailing Craft Design Principles. *Prerequisites: Civ. Eng. 324 and Nav. Arch. 200. (2).*
Application of hydrodynamic and aerodynamic principles to the design of sailing craft.

410. Stress Analysis of Ship Structures. *Prerequisite: Nav. Arch. 310.* I and II. *(3).*
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. 200, 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. Marine Engineering. *Prerequisite: Mech. Eng. 335 or Mech. Eng. 331, Eng. Mech. 324.* I. *(3).*
An introduction to marine engineering covering the same material as Nav. Arch. 330 and Nav. Arch. 331, and intended for students who did not take these courses.

431. Marine Engineering III. *Prerequisite: Nav. Arch. 331 or Nav. Arch. 430.* II. *(3).*
Propulsion machinery design and analysis problems for the marine engineer. Powerplant heat balance, piping stress analysis, vibration problems, plant control, special systems.

440. Ship Dynamics. *Prerequisite: Nav. Arch. 201, and Eng. Mech. 340.* I. *(3).*
The motion of ships at sea: rolling, pitching, seakeeping qualities; steering and maneuvering.

446. Theory of Ship Vibrations I. *Prerequisite: Eng. Mech. 340 and Math. 316.* 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.

450(Meteor.-Ocean. 450). Ocean Engineering II. *Prerequisite: Civ. Eng. 324 (Eng. Mech. 324).* I. *(3).*
Engineering analyses of work systems for operation in and on the ocean, primarily submersibles and offshore drilling platforms. Selected aspects of physical oceanography, underwater acoustics, and instrumentation.

469(Meteor.-Ocean. 469). Underwater Operations. *Prerequisite: permission of instructor.* II. *(3).*
Survey of manned undersea activities in oceanography and ocean engineering. The tools of underwater operations: decompression chambers, habitats, submarines, diving apparatus; pertinent design criteria and applications as based on human hyperbaric physiology and performance. Topics in research diving for engineering and oceanographic studies.

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.

475. Design Project. *Prerequisite: Nav. Arch. 470.* I, II and III*a*. *(3).*
Completion of a design project begun in Nav. Arch. 470. This will usually be the preliminary design of a ship with an emphasis on hull and/or machinery. Team or individual study.

490. Directed Study, Research, and Special Problems. I and II. *(To be arranged).*
Individual study or research.

510. Ship Structure Analysis I. *Prerequisite: Nav. Arch. 410.* I. *(3).*
Analysis of continuous frames, curved beams and variable cross-section structural members. Stiffened plates and cylindrical shells. Bulkheads and other grillage structures. Buckling strength.

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: preceded or accompanied by Eng. Mech. 422 and Math. 450.* I. *(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.* II. *(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.

535. Propulsion Plant Design Decisions. *Prerequisite: Nav. Arch. 430 or Nav. Arch. 331.* II. *(3).*
Selection among alternative power plants. Optimal propulsion powers, and rating of components. Design interactions between hull and machinery. Application of systems analysis techniques to these problems.

550(Meteor.-Ocean. 550). Ocean Engineering III. *Prerequisite: Nav. Arch. 450 (Meteor.-Ocean. 450).* I and II. *(To be arranged).*
Advanced reading and problem resolution in specific areas of ocean engineering, usually followed by presentation of a seminar or preparation of a substantial term paper.

571. Advanced Ship Design. I and II. *(To be arranged).*

572. Economics of Ship Design. *Prerequisite: Nav. Arch. 400.* I. *(3).*
Application of the principles of engineering economics to the design of ships. Selection of a measure of merit. Influence of corporate income tax, leverage, inflation, accelerated depreciation plans. Cost estimates for building and operating ships.

573. Maritime Management. *Prerequisite: Nav. Arch. 572.* II. *(3).*
Application of the principles of engineering economics and management techniques to the operation of ships and shipyards, Chartering arrangements, freight rates, fleet replacement analysis, and impact of federal policies.

574. Computer-Aided Ship Design. *Prerequisite: Nav. Arch. 300 and Eng. 102.* I. *(3).*
Mathematical representation of hull form, lines fairing and design. Computer methods in preliminary ship design and detail design. Hydrodynamic, structural, and economic optimization problems in design. Computer graphics in ship design. Computer aspects of shipyard automation. Software systems for ship design.

590. Advanced Reading 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).*

610(Civ. Eng. 610). Finite Element Methods. *Prerequisite: Eng. 102, and Nav. Arch. 510 or Civ. Eng. 512.* II. *(3).*
Matrix methods. Influence coefficients. Analysis of member systems by the displacement and force methods. Element stiffness matrices. Development of the finite element method—the derivation of the element stiffness matrices for plane stress and plate bending—and its application to plates and shells. Computer problems.

615. Ship Structure Analysis III. *Prerequisite: Nav. Arch. 510. (To be arranged).*
Advances in specific areas of ship structure analysis as revealed by recent research. Lectures, discussions, and assigned readings.

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.* I. *(3).*
A discussion of the basic problems encountered in the application of nuclear reactors to ships.

900. Doctoral Thesis. I and II. *(To be arranged).*

Nuclear Engineering

Department Office: 300 Automotive Engineering Laboratory, 314 West Engineering
See Page 112 for statement on Course Equivalence.

311. Elements of Nuclear Engineering I. *Prerequisite: Physics 240, 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. 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.

315. Nuclear Instrumentation Laboratory. *Prerequisite: preceded or accompanied by Nuc. Eng. 312.* II. *(4).*
An introduction to the devices and techniques most common in nuclear measurements. Topics include the principles of operation of gas-filled, solid state, and scintillation detectors for charged particle, gamma ray, and neutron radiations. Techniques of pulse shaping, counting, and analysis for radiation spectroscopy. Timing and coincidence measurements.

400. Elements of Nuclear Engineering. *Prerequisite: senior standing.* 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. Properties of Atoms and Nuclei. *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.

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 due to neutrons, charged particles, and gamma radiations.

422. Radiation Effects in Semiconductors and Semiconductor Devices. *Prerequisite: Nuc. Eng. 421.* II. *(3).*
Effect of x-and gamma radiations, electrons, and neutrons on semiconductors. Transient radiation effects. Response of diodes, transistors, and integrated circuits to high intensity radiation.

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. Fission Reactors and Powerplants I. *Prerequisite: Nuc. Eng. 312 and Math. 450.* I. *(3).*
A study of nuclear fission reactor theory and powerplant 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. 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.* 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. Plasmas and Controlled Fusion I. *Prerequisite: Nuc. Eng. 312.* II and III*a*. *(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. 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. Quantum Mechanics in Neutron-Nuclear Reactions. *Prerequisite: Nuc. Eng. 411 and Math. 450.* I, II and III*a*. *(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. 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.

515. Nuclear Measurements Laboratory. *Prerequisite: preceded or accompanied by Nuc. Eng. 411.* I. *(4).*
A basic course in the principles of nuclear radiation detectors and their use in radiation instrumentation systems. Characteristics of the more important devices are studied together with some applications in nuclear science. Topics include gamma ray spectroscopy, fast and thermal neutron detection, charged particle measurements, pulse analysis, nuclear event timing, and recent developments in nuclear instrumentation.

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. Nuclear Reactor Kinetics. *Prerequisite: preceded or accompanied by Nuc. Eng. 441 or preceded by Nuc. Eng. 400.* II. *(3).*
Derivation and solution of point reactor kinetic equations; concept of reactivity and inhour equation; reactor transfer function; physical origin and mathematical description of feedback. Linear and nonlinear stability of reactors, and the derivation of the stability criteria. Lyapunov's theory with reactor applications. Space-dependent reactor kinetics and xenon oscillations, coupled core analysis, introduction to reactor noise analysis.

554. Radiation Shielding. *Prerequisite: 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.

561. Nuclear Power Plant Engineering II. *Prerequisite: Nuc. Eng. 441.* 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. Nuclear Power Plant Engineering III. *Prerequisite: Nuc. Eng. 561.* 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.

575(Elec. Eng. 581). Plasma Dynamics and Particle Optics Laboratory. *Prerequisite: preceded or accompanied by a course in plasmas or physical electronics.* II. *(3).*
Experimental techniques for plasma dynamics, electron and ion beam technology, and vacuum technology. Experiments will be on microwave and probe diagnostics of plasmas, plasma instabilities, vacuum systems, plasma generation, electron and ion beam generation and optics, and other topics of current interest. Lectures will be given for background material.

590. 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. 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. 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. 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. Development of neutron balance relations incorporating appropriate neutron-nuclear cross sections.

621. 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. 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. 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. 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. Plasmas and Controlled Fusion II. *Prerequisite: Nuc. Eng. 471.* 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. Plasmas and Controlled Fusion III. *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.* 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. 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. 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

* College of Literature, Science, and the Arts.

Professors—H. R. Crane (Chairman), B. D. Cork, G. W. Ford, P. A. Franken, W. E. Hazen, K. T. Hecht, A. Z. Hendel, J. W. Janecke, L. W. Jones, E. Katz, S. Krimm, A. D. Krisch, O. Laporte, R. R. Lewis, M. J. Longo, W. W. McCormick, D. I. Meyer, O. E. Overseth, W. C. Parkinson, C. W. Peters, J. R. Platt, B. P. Roe, M. H. Ross, T. M. Sanders, Jr., R. H. Sands, N. Sherman, D. A. Sinclair, K. M. Terwilliger, R. S. Tickle, J. C. VanderVelde, G. Weinreich, M. L. Wiedenbeck, L. Wolfenstein, J. C. Zorn.
Associate Professors—J. Bardwick III, C. T. Coffin, W. S. Gray, G. L. Kane, A. L. Read, A. Rich, Y. Tomozawa, J. F. Ward, W. L. Williams, A.C.T. Wu.
Assistant Professors—C. W. Akerlof, J. W. Chapman, H. A. Gould, F. S. Henyey, H. S. Mani, R. Polichar, J. J. Reidy, L. M. Sander, B. E. Springett, C. M. Venkatachalam, D. N. Williams, R. Williams, V. K. Wong, Y. E. Yao.

140. General Physics I. *Prerequisite: Calculus and Physics 141 to be taken concurrently.* I, II, III*a*. *(3).*
A rigorous treatment of basic physics from a modern point of view. Together with Physics 240 and 242, the course covers relativity, vectors, particle mechanics, fields and interactions, fundamental conservation laws, the electromagnetic field, introductory quantum theory, and elementary particles. Two lectures and two recitations per week.

141. Elementary Laboratory I. *To be taken concurrently with Physics 140.* I, II, III*a*. *(1).*
One two-hour period of laboratory per week, designed to accompany Physics 140.

190. Honors Introductory Physics. *Prerequisite: Knowledge of calculus; high school physics assumed.* I. *(5).*
One-term introductory physics course for well-prepared science oriented honors students. To be followed by Physics 191.

191. Honors Physics Laboratory. *Prerequisite: Physics 190.* II. *(1).*
One-term honors physics laboratory course to follow Physics 190.

240. General Physics II. *Prerequisite: Physics 140 or equivalent: Physics 241 to be taken concurrently.* I, II, III*a*. *(3).*
Course description is the same as that shown for Physics 140.

241. Elementary Laboratory II. *To be taken concurrently with Physics 240.* I, II, III*a*. *(1).*
One two-hour period of laboratory per week, designed to accompany Physics 240.

242. General Physics III. *Prerequisite: Physics 240 or equivalent.* I, II. *(3).*
Course description is the same as that shown for Physics 140.

303. Introduction to the Use of Radioactive Isotopes. *Prerequisite: Physics 126 or 240.* 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 240.* 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 240 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 240 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 coordinates; rotating co-ordinate systems, Coriolis force. Introduction to Lagrange's equations.

402. Light. *Prerequisite: Physics 126 or 240 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 240 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 240 and Math. 316 or equivalent.* II. *(3).*
Fundamental physical facts and concepts, thermodynamics 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 240.* 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 240 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.

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 of 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.

601, 602. Particles and Fields.

615, 616. Advanced Mechanics.

617, 618. Continuous Media.

619, 620. Solid State.

621, 622. Quantum Theory of Fields.

623, 624. Advanced Statistical Physics.

625, 626. Theory of Elementary Particles.

627, 628. Experimental High Energy Physics.

631, 632. Advanced Mathematical Physics.

635, 636. Theory of Relativity.

637, 638. Theory of Nuclear Structure.

639, 640. Low Temperature Physics.

643, 644. Advanced Atomic Physics.

655, 656. Advanced Molecular Physics.

665, 666. Contemporary Physics.

715. Special Problems.

801, 802. Preseminar.

901. Thesis.

Science Engineering

Office: 1520 East Engineering
See Page 112 for statement on Course Equivalence.

In addition to the special sequence of Engineering Mechanics and Electrical Engineering courses referred to in the program description, the following courses have been developed specifically for Science Engineering through interdepartmental cooperation. 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.

340. Rate Processes. *Prerequisite: Mech. Eng. 331 or Chem. Eng. 230.* 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.

*Statistics**

Department Office: 1447 Mason Hall

Professors Bell, Dwyer, Ericson, Hill; Associate Professors Starr, Woodroofe; Assistant Professors Gerber, Kurotschka, Landwehr, Owen, Rothman.

* College of Literature, Science, and the Arts. Other courses in statistics are listed in the *Announcements* of that College and the Horace H. Rackham School of Graduate Studies.

300, 301. Introduction to Statistical Reasoning. *Prerequisite: none.* 300, I; 301, II. *(3 each).*
Course is designed to expose a student to the basic ideas underlying statistical reasoning and modern statistical methodology. Topics covered include: rudiments of probability theory; critical discussion of alternative interpretations of probability; statistics as inference and/or decision making; basics of decision theory; the fundamental ideas underlying hypothesis testing and estimation; classical versus Baysian ideas; etc. The basic concepts will be illustrated by use of case studies.

310, 311. Elements of Probability and Mathematical Statistics I and II. *Prerequisite: to be preceded by or taken concurrently with Math. 214 or 315.* I, II, and III*a*. *(3 each).* (Previously Math. 365, 366).
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.

410, 411. Introduction to Probability and Mathematical Statistics I and II. *Prerequisite: Math. 214 or 315.* I, II and III*a*. *(3 each).* (Previously Math. 465, 466).
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. The course is designed primarily for mathematics undergraduates and for graduate students not intending to pursue further formal studies in mathematical statistics. Not open to statistics graduate students.

414, 415. Probability and Mathematical Statistics I and II. *Prerequisite: Math. 450 or 451 or Math. 495.* I, II, and III*a*. *(3 each).* (Previously Math. 468).
The topics covered in this course are virtually the same as in Statistics 410, 411. This course, however, is designed primarily for honors undergraduate students or for graduate students pursuing studies leading to advanced degrees in statistics. This course is prerequisite for virtually all other statistics courses.

425(Math. 425). Introduction to Probability. *(See Math. 425).*

500, 501. Applied Statistics I and II. *Prerequisite: Math. 473 and Statistics 411 or 415 or 311 and permission of the instructor.* 500, I; 501, II. *(3 each).*
Computational methods and use of the computer in statistical analysis. Descriptive methods including presentation and reduction of data; choice of distribution models; regression and correlation; multivariate data; time series. Inferential methods including estimation; hypothesis testing; analysis of variance; goodness of fit; multivariate and sequential analysis. Emphasis will be placed on illustrative examples based on experimental data.

510, 511. Intermediate Statistics I and II. *Prerequisite: Statistics 415 (or 411 and instructor's permission), Math. 417 or Math. 513, preferably to be taken concurrently with Statistics 528, 529.* 510, I; 511, II. *(3 each).* (Previously Math. 661, 662).
Models for data; statistics; distribution theory; an introduction to decision theory; sufficiency and completeness; Bayesian sampling theory and inference; approaches to parametric estimation and properties of the resulting estimates; nonparametric estimation and estimation from large samples. Hypothesis testing through uniformly most powerful unbiased and invariant tests; parametric and nonparametric confidence regions and Bayesian credible regions; the analysis of variance and regression; some simple allocation and design problems; sequential design and analysis of experiments.

525, 526(Math. 525, 526). Mathematical Theory of Probability I and II. (See Math. 525, 526).

528. Probability. *Prerequisite: Math. 451 and one of: Statistics 410, 414, or Math. 425.* I. *(3).*
Probability theory: review of combinatorial results, axiomatic development, conditional probability, independence, random variables and their distributions. Standard distribution functions, expectations, transformations, characteristic functions, laws of large numbers, the central limit theorem.

529. Distribution Theory. *Prerequisite: Statistics 528 or Math. 525.* II. *(3).*
Review of distributions and their transforms; exact distributions in the parametric cases, sampling normal and Poisson processes; exact distributions in the non-parametric case, ranks, order-statistics and/or runs; approximate distributions for finite sample sizes including Tauberian theorems, Pearson curves, Monte Carlo studies. Tools of large sample theory including the delta method, etc. Edgeworth expansions and large deviations. Asymptotic behavior of particular statistics.

530. Applied Probability. *Prerequisite: Statistics 415 or Math. 451 and 525 or permission of the instructor.* I. *(3).*
Generating functions; recurrent events and the renewal equation; random walks; Markov chains and branching processes in discrete time; Markov chains in continuous time with emphasis on birth and death processes, queueing theory. The mathematical models studied will be related to real phenomena.

531. Statistical Analysis of Time Series. *Prerequisite: Statistics 415 and 530.* II. *(3).*
Decomposition of series; trend and regression as a special case of time series; cyclic components; smoothing techniques; the variate difference method; representations including spectrogram periodogram, etc.; stochastic difference equations, autoregressive schemes, moving averages; large sample inference and prediction; covariance structure and spectral densities; hypothesis testing and estimation; applications and other topics.

540,541. Linear Statistical Models I and II. *Prerequisite: Statistics 415 (or Statistics 411 and permission) and Math. 417 or 513.* 540, I; 541, II. *(3 each). (Previously Math. 565, 566)*
Gauss-Markov theorem; one-way, two-way analysis of variance, and complete higher-way layouts; regression; the general linear model and hypothesis, least squares theory; anlysis of covariance; missing observations; multiple comparisons procedures; incomplete blocks, split plot designs, and latin squares; variance component models, mixed models; treatment of residuals; robustness of the methods.

550. Introduction to Decision Theory. *Prerequisite: Statistics 415 or 411 and permission of the instructor.* I. *(3).* (Previously Math. 564).
Axiomatic foundations; utility, subjective probability; decision functions; randomized acts; risk function; admissibility; completeness, Bayes and minimax rules; sufficiency; monotonicity; invariance; estimation problems, two-action problems, multiple decision procedures; preposterior analysis; Empirical Bayes and Compound decision procedures.

551. Bayesian Inference. *Prerequisite: Statistics 415 and 550.* II. *(3).*
Foundations; likelihood principle, non-informative stopping; sequential analysis; choice of priors; stable estimation; conjugate priors; invariance; estimation; credible intervals; hypothesis testing, the Lindley-Jeffreys paradox, the meaning of significance levels; unidentifiability; Behrens-Fisher problem; regression and multivariate problems.

560. Introduction to Non-parametric Statistics. *Prerequisite: Statistics 415 or 411 and permission of the instructor.* II. *(3).* (Previously Math. 569).
Confidence intervals and tests for quantiles, tolerance regions and coverages; estimation by U statistics and linear combination of order statistics; large sample theory for U statistics and order statistics; the sample distribution and its uses including goodness-of-fit tests; rank and permutation tests for several hypotheses including a discussion

of locally most powerful rank and permutation tests; large sample and asympototic efficiency for selected tests.

570. Experimental Design. *Prerequsite: Statistics 415 and 541 or permission of the instructor.* II. *(3).* (Previously Math. 566).
The goals and devices of design with special reference to layouts and the analysis of covariance. The main combinatorial layouts, their uses and limitations and the role of randomization. Sequential aspects of design, especially in the search for conditions of maximal yield; optimal allocation of observations; design considerations remote from layouts; parallels with sampling theory.

575. Theory of Sampling. *Prerequisite: Statistics 415 or 411 and permission of the instructor.* I. *(3).* (Previously Math. 469).
Mathematical foundations of sampling finite populations. Simple random sampling; stratification; ratio and regression estimates; systematic sampling, subsampling; cost functions and choice of optimal designs, estimation procedures.

625, 626. *(See Math. 625, 626).*

628, 629. Probability. *Prerequisite: Statistics 528, 529 or Math. 602.* 628, I; 629, II. *(3 each).*
Advance topics in probability theory with emphasis on continuous parameter stochastic processes. Some probable topics are: infinitely divisible laws and their relation to the central limit problem and processes with independent increments; stochastic integration; foundations of time series and prediction; diffusion processes; stochastic differential equations; and selected topics from the fields of continuous parameter martingales and Markov processes.

630. Topics in Applied Probability. *Prerequisite: Statistics 530 and either Statistics 529 or Math. 626.* I. *(3).*
Advanced topics in applied probability, such as queueing theory, inventory problems, branching processes, stochastic difference and differential equations, etc. The course will study one or two advanced topics in detail rather than attempting to study several in a (necessarily) superficial manner.

640,641. Multivariate Analysis I and II. *Prerequisites: Statistics 511 and 541.* 640, I; 641, II. *(3 each). (Previously Math. 567, 568)*
Topics in multivariate analysis: characterizations and properties of the multivariate normal distribution including the regression function; inference concerning the mean and ordinary, partial and multiple correlation coefficients; Hotelling T^2; the Wishart distribution. Problems in classification and discrimination, canonical correlation, principle components. Clustering, factor analysis, multivariate analysis of variance.

654, 655. Foundations of Statistics I and II. *Prerequisite: Statistics 511, 528 and 551 or permission of instructor.* 654, I; 655, II. *(3 each).* (Previously Math. 663, 664).
Prominent views and current developments in the foundations and philosophy of statistics and probability. Concepts of probability, upper and lower probabilities, utility, basic principles of statistical inference and design are presented critically with emphasis on the neo-Bayesian views.

660, 661. Non-Parametric Statistics I and II. *Prerequisite: Statistics 511, 529 or 626, or permission of the instructor.*
Univariate problems; families of distributions; concept of non-parametric statistics; one sample model; 2-sample, k-sample, and randomness models; bivariate independence; symmetry models; general theory of testing and estimation. Multivariate problems; families of distributions; goodness-of-fit models; 2-sample, k-sample, randomness models; independence and symmetry models; possible general theories. Sequential problems; general properties; goodness-of-fit procedures, procedures based on similarity.

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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 Director, Highway Safety Institute* (Absent on leave from Engineering Mechanics)
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Index

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