UNIVERSITY OF MINNESOTA BULLETIN 1973-75

Institute of Technology

UNIVERSITY OF MINNESOTA

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Institute of Technology

UNIVERSITY OF MINNESOTA

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To Prospective IT Students . . .

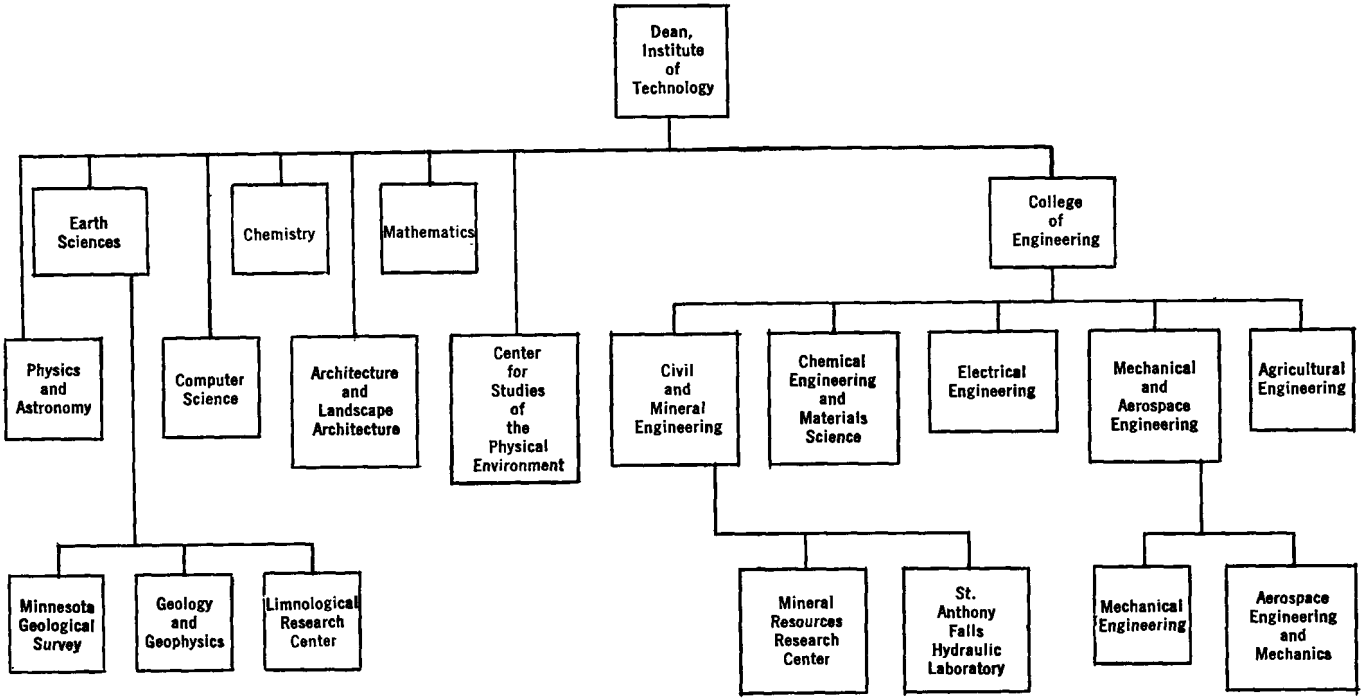
The Institute of Technology includes the general areas of architecture, physical science, mathematics, and engineering. This broad spectrum under a single administrative umbrella is virtually unique in American universities and students are thereby afforded an unusual opportunity for study in a wide spectrum of related fields.

Science and technology, we believe, offer unusual opportunities to motivated men and women. People seeking cures for many of the ills of society such as urban blight, inadequate transportation, shortage of energy sources, and pollution of the environment will need help and advice from those with a broad technical education. At the present time many students and faculty members in IT are working on socially oriented programs such as the experimental city, development of solar energy sources, personalized rapid transit development, solid waste disposal, and studies of air and water pollution, to name only a few. In many cases, these programs offer work experience as well as more formal classroom contact by means of topical courses, seminars, or talks. The problems to be solved are large but the potential for contribution from IT graduates is great.

When you enroll in IT, you will be joining a group of motivated, talented students who have the common goal of obtaining a high quality education. The programs of study which are available to IT students have been recently restructured in order to provide a high degree of flexibility so that an individual may tailor a program to fit his or her own special interests. Each student has a faculty adviser to help in the development of an academic program which is responsive to the student's own interests and fulfills the requirements both of IT and the various accrediting agencies. These faculty advisers are helped and their work supplemented by advising and counseling services in the Office of the Dean. The interests and fields of activity of recent IT graduates are diverse. IT recently prepared a booklet, Careers in Engineering and Science, *which provides case studies of the present professional activities of 16 recent graduates. If you would be interested in receiving a copy of this informative booklet, please inform me and I shall send you a copy.*

Richard A. Swalin
Dean, Institute of Technology
University of Minnesota
Minneapolis, Minnesota 55455

ORGANIZATIONAL CHART
OF THE
INSTITUTE OF TECHNOLOGY



Institute of Technology

I. GENERAL INFORMATION

Degrees Offered

The Institute of Technology offers the Bachelor's degree in architecture and landscape architecture, various branches of science, and the major fields of engineering.

The specific degrees offered are:

Bachelor of Architecture
Bachelor of Landscape Architecture
Bachelor of Environmental Design
Bachelor of Chemical Engineering
Bachelor of Chemistry
Bachelor of Computer Science
Bachelor of Science in Geology
Bachelor of Science in Geophysics
Bachelor of Mathematics
Bachelor of Physics
Bachelor of Aerospace Engineering and Mechanics
Bachelor of Agricultural Engineering
Bachelor of Civil Engineering
Bachelor of Electrical Engineering
Bachelor of Geo-Engineering
Bachelor of Mechanical Engineering
Bachelor of Metallurgical Engineering
Bachelor of Mineral Engineering

Interdisciplinary Programs

Interdisciplinary programs may be planned by students in any of the departments of the Institute of Technology. Some examples of such programs are shown below.

Bioengineering—Project work in bioengineering is available at the undergraduate level. In addition, combinations of electives in biology, physiology, and chemistry, along with related engineering courses, provide an excellent background for the engineer interested in the bioengineering field.

Transportation—Programs in the engineering aspects of transportation problems can be taken in several departments. Project work can involve personalized rapid transit, transportation study and planning, statistical planning, vehicle and system design, community impact studies, and many other closely related projects.

Environmental Engineering—Several IT departments offer work in environmental engineering with emphasis on air pollution, energy utilization emission studies, and environmental design. In addition, environmental work relating to water quality and resources, solid waste disposal, noise pollution, society involvement, etc., is available in connection with other majors.

Nuclear Engineering—An interdisciplinary program in nuclear engineering is available in several departments combining course work in mechanical engineering, chemical engineering, and physics at the upper division level.

Engineering Intern Program—An engineering intern program is available during the last 2 years of study in several IT departments. Special application must be made prior to January 1 of the sophomore year. The programs provide applied engineering training during alternate quarters of industrial assignments with selected established industries. The student is registered in the University during work periods and at all times is considered a regular full-time University student.

Acoustics—The study of acoustics traditionally crosses academic departmental boundaries and finds application in widely separated engineering fields. Of interest are environmental aspects, especially noise, its generation and effects on man and its abatement. Cross-disciplinary programs in this field may be planned in a number of IT departments.

Business Minor—Engineering and business are obviously closely related. By a proper choice of undergraduate elective courses in such areas as economics, accounting, statistics, psychology, management, etc., qualified students may enter the Graduate School of Business Administration after receiving a Bachelor's degree in engineering and may then earn an M.B.A. degree.

There are numerous other areas in which programs can be planned which cut across conventional departmental curricula. For further information students should contact their departmental office or 105 Main Engineering (Office of the Assistant Dean for Student Affairs).

Admission Requirements

Equal Opportunity—The Board of Regents has committed itself and the University of Minnesota to the policy that there shall be no discrimination in the treatment of persons because of race, creed, color, sex, or national origin. This is a guiding policy in the admission of students in all colleges and in their academic pursuits. It is also to be a governing principle in University-owned and University-approved housing, in food services, student unions, extracurricular activities, and all other student and staff services. This policy must also be adhered to in the employment of students either by the University or by outsiders through the University and in the employment of faculty and civil service staff.

Admission as a Freshman—In order to qualify for admission as a freshman in the Institute of Technology the applicant should complete high school mathematics including topics in beginning and intermediate algebra, geometry of two and three dimensions, and trigonometry. It is also strongly recommended that students take physics and chemistry.

In addition, admission to the Institute of Technology is based upon the high school rank and either the ACT mathematics and natural science tests or the mathematics and verbal portions of the Scholastic Achievement Tests (SAT).

Early Admission—Outstanding high school students who have not yet graduated may be admitted to the University, usually after the junior year. Such students must be sufficiently mature to adjust to University life and work. Personal interviews, comprehensive testing, and letters of recommendation from the high school principal or counselor and the parents are required. Fall quarter applicants should apply in the winter or early spring, using the regular application form. A student admitted under this plan normally would not receive a high school diploma.

Admission with Advanced Standing—Students with credits from other accredited colleges or universities may, if admitted, enter with "advanced standing" —that is, with credit for acceptable courses satisfactorily completed.

Students should make application and have all transcripts on file with the Office of Admissions and Records more than a month before the beginning of the quarter in which they wish to enter. July 15 is the deadline for fall quarter; certain specialized programs have earlier deadlines as noted in the college bulletins.

If the student has less than 1 year of advanced work, he must meet regular requirements for admission from high school. He will receive credit for college courses completed satisfactorily. He must file official college transcripts to cover all work done, whether it has been satisfactory or unsatisfactory, including extension or independent study courses taken at the University of Minnesota.

Admission as an Adult Special—Men and women who want individual courses or groups of courses to meet special personal needs may be considered for admission to the individual curricula as "adult special" students. Usually these students are required to have Bachelor's degrees. A student asking admission as an adult special student should obtain an application blank at the Office of Admissions and Records and file transcripts of all college work. Applications should be filed well in advance of the quarter of entrance. Admitted applicants will be required to fill out a One-Year Plan with a departmental adviser. Adult special students are not candidates for degrees, but subsequent admission to a degree program is possible on recommendation of the college. In such case, credit earned as an adult special student will be applied when possible. Only 1 quarter of work as an adult special student may be used for a Graduate School degree. Admission is completed through the Office of Admissions and Records. Restrictions on admission of nonresident undergraduate students apply also to admission of adult special students.

Admissions Advising—Any student who wishes to discuss his individual admission situation is welcome to do so and may arrange an interview by contacting the Office of the Assistant Dean, 105 Main Engineering Building. Students should bring information such as high school transcripts, test results, records of college work, and other information useful for such advising.

Student Counseling Services

FACULTY ADVISER

Every new student is assigned a faculty adviser from the department in which he seeks his degree at the time of registration in the Institute of Technology. Students who select a major and have inquiries concerning their adviser, including a

request for a change in adviser within the department, should go to the departmental office. Students who wish to delay selecting a major for 1 year are titled "IT Unclassified" and will be assigned a faculty adviser, in the Central Advising Program, by the director of Lower Division Programs, 104 Main Engineering Building. If a student wishes to change major it is necessary to go to 105 Main Engineering Building for processing.

During the fall quarter of the year, new freshmen should consult with their advisers to plan their programs for the remainder of the academic year. The program of studies for the second year should be planned during the spring quarter in consultation with the adviser. Any changes in the program must also be made in consultation with the adviser and will be accepted for registration only when they have been approved by the adviser.

Professional counselors from the Student Counseling Bureau maintain regular office hours in 104 Main Engineering Building. Students with personal problems may make an appointment to see a counselor by coming to this room.

PROJECT TECHNOLOGY POWER

In an increasingly technological society, all citizens should share, not only in its products, but in its decisions and in its processes of production. However, while one-sixth of the nation's population is nonwhite, only 1 percent of its engineers are minority.

IT is therefore making a vigorous effort to improve its performance in graduating nonwhite and/or low-income students through a collection of recruitment and retention programs called Project Technology Power. Academic aids for IT students served by this program include special tutorial assistance, dormitory residence scholarships, and when possible, part-time employment in a technological environment. The project also runs motivational programs for inner-city secondary school students, in which all IT students are invited to serve.

UNCLASSIFIED MAJOR DEPARTMENT

Students who are interested in majoring in engineering and science but are uncertain about a specific major in these fields should select "IT Unclassified" as a major. Freshmen of this category are assigned an adviser in the Central Advising Office, 104 Main Engineering Building, which also serves as the departmental office for unclassified students.

Advisers are faculty selected from the various IT departments who are available for regularly scheduled hours to meet with advisees. In addition to assisting students with their academic programs appropriate for the various IT fields, the advisers provide special counseling in career planning including referrals to other faculty and visits to IT laboratories and to local industries. Unclassified students are usually prepared to make a judicious choice of major by the end of the first year. The procedure for transfer is a simple one and can be accomplished by consulting with the adviser.

New advanced-standing students and transfers from other IT departments or from within the University who select the unclassified category are provided similar assistance as described above for freshmen.

TUTORING PROGRAMS

For several years the Institute of Technology has provided tutorial assistance for its students in mathematics, physics, chemistry, and various other IT courses. Service has been available for all students at various locations—on campus, in the residence halls, and at select metropolitan high schools. The intent is to continue the tutoring program as long as funds are available, since it has been found that the service is greatly appreciated by the students and it provides the opportunity to develop skills in the required subjects to the fullest of a student's potential.

Specifically, peer tutorial assistance is available during morning and afternoon hours, Monday through Friday, 104 Main Engineering Building. Two to three tutors hold regularly scheduled hours, generally from 7:00 to 10:00 p.m. Sunday through Thursday in Frontier and Territorial Halls. Several metropolitan high schools, such as Minneapolis Washburn, St. Paul Johnson, Edina East, and Mounds View, are staffed by a tutor from 7:00 to 9:00 p.m., usually Tuesday and Wednesday evenings. The tutors are selected from the junior and senior honor students who are enrolled in IT and demonstrate an interest and willingness to work with students.

In addition, the Mathematics, Physics, Chemistry and Aerospace Engineering and Mechanics Department staffs designated study rooms, within the departments, with teaching assistants who provide help with problems and subject matter taught by the department, i.e. mathematics, physics, chemistry, or mechanics courses. Departmental service is during daytime hours, usually 9:00 a.m. to 4:00 p.m.

Inquiries concerning the tutorial program should be directed to the Director of Lower Division Programs, 104 Main Engineering Building.

INSTITUTE OF TECHNOLOGY PLACEMENT SERVICE

The Placement Service, located in the Experimental Engineering Building, is available to assist the graduating senior or advanced degree candidate in securing employment. Assistance is also available to the undergraduate seeking summer employment. The Placement Service arranges appointments with visiting interviewers, maintains a library of information on companies and government agencies who are prospective employers, and provides counsel to the graduate in helping him find the position best suited to his aptitudes, training, and interests.

Continuing Education

Four years in an engineering school will not make a finished engineer of anyone; it is a step along a path of a continually maturing process. The basic preparation in science and engineering science takes such a large fraction of an undergraduate's effort that the time available for professional studies enables a student to do little more than sample a few elements of his chosen field. Each branch of engineering comprises a wide spectrum of technical disciplines; a newly graduated engineer may be employed in research and development, design, production and construction, or in marketing engineering. Each of these technical disciplines, each of these types of engineering activity requires specialized knowledge on the part of the graduate. Because of this and because of the rapid technical advances

constantly being made, engineers find continuing education a necessary part of their whole professional career. Most employers recognize this and encourage it by allowing released time for formal course work and paying all or part of the tuition for courses successfully completed.

Some of the process of continuing education is done individually through technical reading in current books and periodicals. Some is handled by large companies through in-house courses on job-related subjects. However, most engineers realize that they must broaden their technical horizons in order to prepare themselves for promotion, for change of job area, or to keep from becoming technologically obsolete.

The Institute of Technology has a number of programs to help the working engineer in the formal part of his continuing education activities. Primarily for the B.S. graduate out of school only a few years, it cooperates with the Graduate School in post-baccalaureate education leading to the master of science and the doctor of philosophy degrees for those engineers interested in a career primarily in research and development. The master of engineering program in a specific field of engineering is available for the young engineer who wants specialized preparation for a career in engineering design in his chosen field. The Professional Development Recognition Program leading to diplomas for successful completion of successive increments of educational growth is available for working engineers of all ages as a method of giving formal recognition to the successive steps in an individual's continuing personal development program over his entire career. Any qualified applicant may register as an Adult Special for one or more specific courses. Prospective registrants are encouraged to discuss these programs with a representative of the appropriate department of science, engineering or architecture before making formal application for admission. Further information on the specific requirements may be found under the appropriate headings of this bulletin or in the *Graduate School Bulletin.* Information on appropriate forms and procedures may be obtained for any of these programs by writing to

Office of the Assistant Dean for Student Affairs
Institute of Technology
105 Main Engineering Building
University of Minnesota
Minneapolis, Minnesota 55455

Formal course work appropriate for any of these programs may be taken from among the offerings of the Institute of Technology during the regular school year. Many technical courses may be taken at industrial plants in the Twin Cities and Rochester by means of microwave TV under the UNITE system which is described elsewhere in this bulletin. Several short courses are available in specialist areas, primarily during the Summer Session. Representatives of the various departments can give information about short courses available elsewhere or under other auspices.

UNITE INSTRUCTIONAL TELEVISION

Engineers and scientists in some segments of Minnesota industry can now take regular University courses at their places of employment, thereby avoiding the time and inconvenience of traveling to the Minneapolis Campus. This is accomplished through UNITE (UNiversity-Industry Television for Education), an instructional television system for the delivery of in-plant continuing education.

Program offerings each quarter include some 20 graduate and upper division courses in the regular daytime curriculum, plus a selection of specially developed courses and seminars.

Classes originate in specially equipped studio classrooms with on-campus students present. Communication with off-campus classrooms at plant sites takes place in the 2500 megahertz (ITFS) microwave band. The system is interactive, i.e., students at all sites talk back to the main classroom and participate in class discussion.

Each participating company helps support the system through a special fee based on the number of credit hours for which its employees are enrolled. This surcharge is separate from tuition, which is paid by the student or by his company, depending on individual company policy.

The growing list of participating organizations includes the following: Honeywell Inc., IBM Corporation, 3M Company, Northern States Power Company, Sperry Univac, U.S. Bureau of Mines.

PROFESSIONAL DEVELOPMENT RECOGNITION PROGRAM

This is a joint program of the Institute of Technology and Continuing Education and Extension, providing engineers and scientists a means for planning, pursuing, and receiving recognition for personalized continuing professional education programs throughout their professional lives. Students interested in the program must have a minimum of a Bachelor's degree. Most programs can be completed in 2 calendar years.

MASTER OF ENGINEERING PROGRAM

It is widely recognized that it is impossible to prepare a student for design work of professional engineering caliber in a 4-year program. Many graduates move into engineering sales or management and take post-baccalaureate studies in business administration to further their career objectives. Some go into research and development and study for an M.S. or Ph.D. degree. A large fraction of working engineers design systems or components and feel the need for further education with a design flavor in an engineering specialty.

The Institute of Technology offers a 1-calendar year, design-oriented program both for the recent graduate who is sure of his chosen specialty and for the engineer who has been on the job for several years and now desires to improve his technical capabilities. This program leads to the master of engineering (M.E.) degree in any of the engineering curricula. A student seeking this degree will usually take five or six courses of a professional or design nature in his specialty and two or three courses in an appropriate minor field such as business, economics, statistics, political science, geography, science or some related engineering discipline. In addition, he will complete a design project equivalent to 4 or 5 months' total effort under faculty supervision and often with the active advice and assistance of a working engineer.

This program is primarily designed to give the recent graduate with a Bachelor's degree in engineering specialist preparation for design work of an advanced nature. It has completely different objectives from the research-oriented M.S. pro-

gram and the prospective student should think of it as a terminal program designed primarily to make him more effective as a design engineer.

The distinction between the objectives of this program and that of the master of science depends on intent. Design concerns itself with the application of the knowledge and methods of engineering and of the physical and social sciences for the adaptation of materials and sources of power to the use of mankind. Thus, any study which focuses on the engineering application rather than on the method or material behavior may properly be called a design study.

Admission—Prospective students should inquire from the individual departments for appropriate forms and other information necessary. The criteria to be considered for admission will be:

a. Interest in and aptitude for design-oriented and creative programs as evidenced by performance in undergraduate laboratory, professional, and design courses.
b. Technical reports or other evidence of performance in industrial design. Reports on undergraduate projects.
c. Performance in undergraduate curricula. Greatest weight will be placed upon upper division and other professionally oriented courses. Unless there is evidence to the contrary, a GPA of 2.50 or better will normally be considered acceptable for admission. In cases that do not fit the above criteria, consideration will be given to recommendations from faculty or practicing engineers.

Interested students should inquire at their department office for additional information.

Computer Facilities

Digital computers have become common working tools for most engineers within the past few years. In recognition of this, the Institute of Technology in cooperation with the University Computer Services has established open laboratories with time-share terminals of the Minnesota Educational Regional Interactive Time Share System (MERITSS). These terminals are available to any IT student at any time during the working day and during many evening and weekend hours depending on demand. They operate in an interactive mode with a CDC 6400 computer and through it with the much larger CDC 6600 model. The 6600 can also be used in a batch mode for class assignments or special projects under faculty supervision.

In addition to these general purpose computers, students have access to a large number of special purpose ones ranging in size from small table top units for data reduction in laboratories to larger, dedicated models for special projects in computer sciences and electrical engineering.

While many entering students have learned programming and computer use in high school, it is usually at the elementary level (BASIC language). A series of graded courses which may be entered at different levels is offered in the freshman year both for them and for students with no prior training by the Department of Computer, Information, and Control Sciences (CICS). These courses bring the student to the level of more sophisticated programming, using both the 6400 and 6600 systems and introduce other languages such as FORTRAN, ALGOL, and

APL. All students are thus prepared to use digital computers in their subsequent course work.

Although digital computers are the most widely used computational aid in engineering work, analog computers also see a great deal of service for some applications. Each engineering department in IT has one or more analog computers for instructional use, in addition to those reserved for research projects. They are used for such diverse student projects as the investigation of aircraft, spacecraft and rapid transit dynamics, transients in chemical process industry, flow-in hydraulic systems, and feedback control stability.

University Computer Services also administers a hybrid computer system consisting of two EAI-680 analog computers interacting with a 1700 CDC digital system. While there are a number of applications of this system of interest to undergraduates, perhaps the most important is in the field of computer graphics. This enables the fledgling architect to see how the roof of his design shades the house at different seasons of the year in animation on a special TV screen. It lets the civil engineering student examine the influence of new dams and channels on the flow patterns of a town, a county, or an entire state using the same equipment. It is hoped that in the future, students will be able to use this or similar equipment to study graphics in its most general form.

The use of computers of all sizes and types is developing so rapidly that it is difficult to predict all applications even a few years ahead. It is the stated purpose of IT to make sure that all of its graduates have hands-on experience with enough different computers during their undergraduate education that they will be thoroughly at home in their use on the job.

Student Activities

Professional Societies—Branches of the following national professional societies are maintained at the University of Minnesota by students and faculty members: American Chemical Society, American Institute of Chemical Engineers, American Institute of Mining and Metallurgical Engineers, American Institute of Physics, American Society of Civil Engineers, American Society of Mechanical Engineers, American Society of Agricultural Engineers, American Institute of Aeronautics and Astronautics, and the Institute of Electrical and Electronic Engineers. In addition there are the Architectural Society, the School of Mineral and Metallurgical Engineering Society, the University of Minnesota Flying Club, the Geology Club, and the Minnesota Society of Professional Engineers.

Honorary Scholastic Fraternities—The honorary scholastic fraternities in the Institute of Technology promote the high standards of the engineering profession by conferring memberships, awards, and other honors on undergraduates distinguished for scholastic achievement and for character. Of these honorary fraternities, only Tau Beta Pi selects its members from students in all undergraduate departments of the Institute of Technology. The others confine their membership to students from one department: Chi Epsilon (Civil Engineering); Eta Kappa Nu (Electrical Engineering); Phi Lambda Upsilon (Chemistry); Pi Tau Sigma (Mechanical Engineering); and Sigma Gamma Tau (Aerospace Engineering and Mechanics). These fraternities normally elect their undergraduate members from the third- and fourth-year class on the basis of scholarship as measured by class rank and of character as judged by fellow students and faculty.

Plumb Bob—Plumb Bob is a senior honorary leadership and service fraternity. Its 12 members serve during their senior year, but their names are not announced until Engineers' Day (IT Week). Plumb Bob works to create and maintain a spirit of fellowship and cooperation among the students of the Institute of Technology and to further the interests of the institute and the University. Its members are chosen for their character, leadership, and service by a committee of students and faculty.

IT Student Board—The IT Student Board is the executive body of the students in the Institute of Technology. The board enables the students to act as a unit in matters affecting the general interests of the institute and the University. The Student Board has general supervision and responsibility for Engineers' Day (IT Week) and other student activities in the Institute of Technology.

Minnesota Technolog and Technolog Board—The *Minnesota Technolog* is the undergraduate technical magazine of the Institute of Technology. It is a monthly publication produced by the students under the direction of an editorial and business staff selected by the student body. The policies of the magizine are determined by the Technolog Board. The Technolog Board selects the editor-in-chief and business manager and assists them in their work.

Scholarships, Employment Services, and Financial Assistance for Students

University Undergraduate Placement Service and Student Loans—Information on University undergraduate services and student loans may be obtained from the *General Information Bulletin.*

Job Opportunities in Institute of Technology Research Facilities—Opportunities for both graduate and undergraduate research are available in several institute research laboratories, and part-time employment is in many cases available to qualified and interested students. Since a complete listing of these facilities and opportunities is not possible, students should inquire at the individual departments for further information.

Undergraduate Scholarships and Awards—The following scholarships and awards are available to students in the Institute of Technology. Entering freshmen interested in loans, scholarships, or grants should contact their high school guidance office for application forms. Information regarding these and other scholarships available to all students in the University may be obtained from the Office of Student Financial Aid, after 2 quarters of attendance.

For description of scholarships herewith, see those under individual departments and schools as well as those under "All Divisions." Unless otherwise noted, one award is made each year. Students are advised to read the Official Daily Bulletin the first week of winter quarter each year for details and procedures to follow to make application.

ALL DIVISIONS

Alcoa Foundation Scholarships: For engineering undergraduates who have shown exceptional promise. Four $750 awards.

Boeing Company Scholarships: For aeronautical, electrical, mechanical, and civil engineering students for use in the third year (may be renewed for fourth-year undergraduates). Amount is tuition plus student services fee at the resident rate. Four awards annually.

J. Miller Brown Scholarship: Awarded annually to any one of the five top students of the freshman class based upon merit without regard to financial need. Amount is $125.

Ellerbe Engineering Scholarships: For undergraduates with majors in civil, electrical, and mechanical engineering. Preference given to entering freshmen or students with advanced standing who are in the upper 10 percent of their classes. Amount is $300. Three awards annually.

IT Alumni Association Scholarship: For undergraduates in any department of the Institute of Technology. Amount is $200-$400.

Minnegasco Engineering Scholarship: To aid and encourage students in engineering, especially chemical and mechanical. Entering freshmen, qualified transfer students, and students with advanced standing are eligible. Usually covers tuition for at least 1 quarter.

Minneapolis-Honeywell Award in Engineering and Science: For distinguished performance of third- and fourth-year students in engineering and science. Amount is $250-$300.

Minnesota Mining and Manufacturing Company Scholarship: For one or more scholarships in engineering. Amount is tuition plus student services fee.

Minnesota Society of Professional Engineers Special Scholarship: To aid and encourage students of minority races in engineering. Entering freshmen, qualified transfer students, and students with advanced standing are eligible. Amount varies.

North Star Concrete Company University of Minnesota Scholarship: For one student entering his fourth year who is enrolled in one of the following majors: civil engineering or architecture. Amount is $500.

Northland Aluminum Products Scholarship: A scholarship of $500 per year is available to a qualified undergraduate majoring in chemical engineering, industrial engineering, mechanical engineering, electrical engineering, or metallurgy-materials science. The scholarship is renewable.

Harlow C. Richardson Scholarship: For undergraduates in the Institute of Technology with demonstrated interest in the humanities. Amount is minimum of tuition and student services fees. Six or more awards annually.

Sigma Xi Scholarships (Minnesota Chapter, University of Minnesota): For undergraduate with aptitude and proficiency in some field of scientific endeavor. Amount is $400.

Alfred P. Sloan Foundation Scholarship: To students in the arts and sciences on the basis of scholastic achievement and community responsibility.

William Sturm Memorial Scholarship Fund: For outstanding recipient of the Ellerbe and Company Engineering Scholarship. Amount is $100.

Sundstrand Foundation Scholarship Fund: For students in mechanical engineering, electrical engineering, metallurgical engineering, industrial engineering, or any other technical curricula approved by the Board of Directors of Sundstrand Foundation. A scholarship awarded to a freshman shall be renewable for 3 additional years.

Nellie S. Trufant Memorial Scholarship in Engineering: For the use of any qualified student in the Institute of Technology in his third or fourth year.

Twin Cities Chapter of the American Society of Tool Engineers (Louis Walton Memorial) Scholarship: For fourth-year Institute of Technology students majoring in a phase of engineering leading to a career in tool engineering. Amount is $100.

Twin Lakes Auxiliary M.S.P.E. Scholarship Fund: An initial gift of $100 from the Minnesota Society of Professional Engineers Twin Lakes Chapter Auxiliary established a scholarship fund to provide assistance to a promising engineering student.

AEROSPACE ENGINEERING AND MECHANICS

Aero-Alumni Scholarship: For students majoring in aerospace engineering and mechanics. Amount is tuition and fees.

Irvin M. Nestigen Memorial Loan Fund: Loans may be made to aerospace engineering students without interest until graduation, and at 3 percent thereafter.

Rosemount Engineering Company Instrumentation Award: To the graduate or undergraduate student in aerospace engineering and mechanics or mechanical engineering judged by the departments to have the greatest potential for the design and development of industrial aircraft and/or space instrumentation. Award is $400.

AGRICULTURAL ENGINEERING

William Boss Agricultural Engineering Scholarship: (Specialty Manufacturing Company, St. Paul): For entering freshman in agricultural engineering. Amount is $500.

Farmhand Agricultural Engineering Scholarship: For entering freshman or undergraduate in agricultural engineering. Amount is $300.

Minnesota Concrete Drain Tile Manufacturers' Association Scholarship: For student in agricultural engineering or mechanized agriculture with preference given to a freshman. Amount is $300.

Northern States Power Company Agricultural Engineering Scholarship: For entering freshman or undergraduate in agricultural engineering. Amount is $300.

Northwest Farm Equipment Association Agricultural Engineering Scholarship: For academically qualified students in the College of Agriculture or the Institute of Technology. Amount is $300.

Other: Students enrolling in agricultural engineering should inquire through the department for information about scholarships administered under the jurisdiction of the St. Paul Campus Scholarship Committee.

ARCHITECTURE

The American Institute of Architects and the American Institute of Architects Foundation, Inc., Scholarship Program: For undergraduate and graduate students in architecture. Normally three awards annually.

Ellerbe Architectural Scholarships: For students who have completed Design II in architecture. Amount is $300. Three awards annually.

Flour City Architectural Education Fund (Flour City Architectural Metals Division, Hupp Corporation, Minneapolis): For undergraduates with advanced standing in architecture. Amount varies.

Horty, Elving Architectural Fund: Monies and any interest to be utilized by the School of Architecture.

Idstrom Architectural Fund: For advanced students in architecture. Amount varies.

Professor Roy Childs Jones Memorial Scholarships: For advanced students in architecture. Amount varies.

Mankato Stone Company Education Fund: For undergraduates with advanced standing in architecture. Amount varies.

The Minneapolis Gas Company Total Energy Fund: For student who designs, in competition with other students, the best project which would be heated, cooled, and powered via gas total energy. Amount is $250.

Minnesota Lathing and Plastering Bureau Scholarship: For students in the School of Architecture. Amount is $500.

Minnesota Society of Architects Scholarship Fund: For students in the School of Architecture. Amount varies.

Northern States Power Scholarship: For undergraduates with advanced standing in architecture. Amount is $250.

Northern States Power Prize: For winner(s) of student design competition. Amount is $250.

A. C. Ochs Brick and Tile Company Scholarship: For advanced students in architecture. Amount is $250.

Wells H. Paschall Memorial in Architecture Fund: Four awards to students in the School of Architecture.

Ralph Rapson F.A.I.A. Architectural Education Fund.

Setter, Leach and Lindstrom, Incorporated, Scholarship: For advanced students in architecture. Amount is $400.

Sverdrup and Parcel and Associates, Incorporated, Scholarship: One $600 scholarship to a fourth-year student who is a United States citizen and who has high academic achievement.

Rollin B. Child, Incorporated, Education Fund: For students in the School of Architecture. Amount varies.

Thomas F. Ellerbe Prize in Architecture (sponsored by the Co-operative Foundation): For excellence in study of buildings for cooperatives. Amount is $300. One to three awards annually.

Minnegasco Architectural Scholarship and Prize: For undergraduates in the School of Architecture.

Alpha Rho Chi Book Awards: For outstanding research in architectural history.

Alpha Rho Chi Medal: For architectural ability and student leadership.

American Institute of Architects Medal: For highest scholastic standing in graduating class during academic year.

CHEMICAL ENGINEERING AND CHEMISTRY

American Institute of Chemical Engineers Scholarship: To a chemical engineering student who is active in the A.I.Ch.E.

Peteris Auzins Scholarship: To a promising physics or chemistry student.

John P. Fridley Foundation Scholarship: For undergraduate students in engineering with preference to those in chemical engineering. Up to $1,000.

I. M. Kolthoff Scholarship in Analytical Chemistry Fund.

M. Cannon Sneed Memorial Scholarship in Chemistry: To provide assistance to students in the field of inorganic chemistry who demonstrate great promise for future achievement, and who are in need.

Standard Oil Company of California Scholarship: For use of advanced student in chemical engineering. Amount is $750.

George T. Walker Fund: To aid deserving students in the Department of Chemistry. Amount varies.

CIVIL ENGINEERING

Tom Burns Scholarship: To a promising student in civil engineering.

Minnesota Society of Professional Engineers Special Scholarship: See description under All Divisions.

Minnesota Surveyors and Engineers Society Highway Engineering Scholarships: For undergraduates in civil engineering with emphasis on highway engineering. Students must have completed 2 years in the Institute of Technology. Students may apply to Personnel Office, State Highway Department, for summer employment. Amount is $250 or $350 for third- or fourth-year students.

North Star Concrete Company University of Minnesota Scholarship: For one student entering his fourth year who is enrolled in one of the following majors: civil engineering or architecture. Amount is $500.

ELECTRICAL ENGINEERING

Pillsbury Company Scholarships: For junior or senior students in mechanical or electrical engineering on the basis of academic ability and record, vocational promise, leadership potential, personal attributes, and financial need.

Schlumberger Foundation Scholarship: For students in electrical or mechanical engineering or physics. Amount is $500.

GEOLOGY AND GEOPHYSICS

Geology Service Fund: Special grants to students of the Department of Geology and Geophysics.

David K. Jensen Memorial Scholarship: To undergraduate students planning to continue with graduate work (or to graduate students) in geology or geophysics.

MATHEMATICS

Dr. Halbert C. and Mrs. C. Christofferson Scholarship: To a promising student in mathematics.

John Torrence Tate Memorial Scholarship: See description under Physics scholarships. See scholarships under All Divisions.

MECHANICAL ENGINEERING

Adolph O. Lee Scholarship: To one or more needy mechanical or industrial engineering students.

Pillsbury Company Scholarships: See description under Electrical Engineering scholarships.

Rosemount Engineering Company Instrumentation Award: To the graduate or undergraduate student in aerospace engineering and mechanics or mechanical engineering judged by the departments to have the greatest potential for the design and development of industrial aircraft and/or space instrumentation. Award is $400.

Schlumberger Foundation Scholarship: See description under Electrical Engineering scholarships.

Standard Oil Company of California Scholarship: For undergraduate in mechanical engineering. Amount is $750.

Carl Warner Scholarship: To assist industrial engineering students whose training in engineering would qualify them as industrial engineering management trainees.

METALLURGY/MATERIALS SCIENCE

International Nickel Company Scholarship: For entering freshmen in engineering with preference to mineral, geological, and metallurgical engineering. Renewable annually. Amount is $300 plus tuition and fees.

MINERAL RESOURCES AND GEO-ENGINEERING

M. A. Hanna Company Scholarships: For Hanna Company employees, their sons, or relatives who wish to attend the University on the Minneapolis Campus, or Michigan College of Technology, Houghton, Michigan. Preference given to those enrolled in mineral technology (mineral and metallurgical engineering), but other students in IT may also be eligible. Amount is $500. Entering students apply through their high school by January 1 each year; University students follow regular procedure. Two awards each year, renewable if student maintains at least a 2.80 grade point average.

Mineral Industry Education Fund Sponsored by the Minnesota Section, American Institute of Mining, Metallurgical, and Petroleum Engineers: For graduate and undergraduate students pursuing degrees in mineral and geological engineering. Grants from $500 to $1,500 per year. The Mineral Industry Education Fund in cooperation with the office of Student Financial Aid also administers the Cleveland-Cliffs Iron Company, E. J. Longyear Memorial, and Mesabi Tire Co., Inc., Scholarship.

PHYSICS

Radio Corporation of America Scholarships: For undergraduates with advanced standing in physics or electrical engineering who are specializing in radio or electronics. Amount is $400. Two awards annually.

Schlumberger Foundation Scholarship: See description under Electrical Engineering scholarships.

John Torrence Tate Memorial Scholarship (memorial gifts from friends of the late Professor John T. Tate): For students with advanced standing in astronomy, chemistry, mathematics, or physics. Amount is $200-$250. Two awards annually.

Professionalism and Professional Registration

Registration as an engineer is a legal requirement for certain kinds of practice. A Professional License is a requirement before one may use the designation of Engineer in any legal connection. Many engineers in industry who have no current legal obligation to be registered have obtained licenses to show their support of the concept of a legal recognition of the professional standing of an engineer or because they might find it useful for future employment in a government agency or in private practice.

The license is awarded in most states to those graduates of an accredited engineering curriculum who have passed an examination in the fundamentals of engineering and who have demonstrated their competence by a number of years of appropriate experience. The examination in the fundamentals covers materials studied in undergraduate curricula. For the convenience of students, this examination is given at the University in the spring of every year and may be taken by students in their senior year. Further information and application forms may be had from

Executive Secretary
Minnesota State Board of Registration
for Architects, Engineers, and Land Surveyors
1512 Pioneer Building
St. Paul, Minnesota 55101

Engineers, scientists, and architects usually find it helps their professional development to join and be active in one or more technical or professional societies. Many of these societies have student chapters at the University. These chapters give students the opportunity to participate in activities of the parent society, to gain experience in the conduct of technical meetings, and to meet senior members of the societies. In addition, regular membership in the society is facilitated upon graduation and any entrance fee is reduced or waived for former student members.

II. CURRICULUM REQUIREMENTS

First-Year Programs

The first-year program for most students follows one of the options listed below. Modifications to the programs may be made dependent upon the student's particular major choice. Unclassified major students would generally follow the option in which their major interest lies.

OPTION A

(Agricultural Engineering, Aerospace Engineering, Civil Engineering, Computer Science, Electrical Engineering, Geological Engineering, Geology, Geophysics, Mathematics, Mechanical Engineering, Mineral Engineering, Physics)

	Credits—f,w,s		
Math 1211, 1221, 1231—Analysis I, II, III (or) Math 1311, 1321, 1331—Computer Calculus	5	5	5
Comp 1001, 1002—Introductory Composition (or) Comm 1001, 1002—Communications	4	4	..
Phys 1271, 1281—General Physics	..	4	4
Phys 1275, 1285—Physics Lab	..	1	1
Elective*	4-5	..	4-5
	13-14	14	14-15

OPTION B

(Chemical Engineering, Chemistry, Materials Science)

	Credits—f,w,s		
Math 1211, 1221, 1231—Analysis I, II, III (or) Math 1311, 1321, 1331—Computer Calculus	5	5	5
Chem 1031, 1032, 1034—General Principles	5	5	5
Comp 1001, 1002—Introductory Composition (or) Comm 1001, 1002—Communications	4	4	..
Nontechnical Elective	..	..	4
	14	14	14

OPTION C

(Architecture, Environmental Design)

	Credits—f,w,s		
Math 1211, 1221, 1231—Analysis I, II, III (or) Math 1311, 1321, 1331—Computer Analysis	5	5	5
Comp 1001, 1002—Introductory Composition (or) Comm 1001, 1002—Communications	4	4	..
Arch 1021, 1022, 1023—History of Environmental Development	4	4	4
Phys 1121, 1122—Physics for Architects	..	4	4
Nontechnical Elective	..	..	4
	13	18	18

OPTION D

(Landscape Architecture)

See department curriculum.

* Elective may be in computer science, introduction to engineering, or a nontechnical elective.

In all of the options listed above and in the departmental options that follow, students have the option of taking either Math 1211-1221-1231 (Analysis I, II, III) or Math 1311-1321-1331 (Computer Calculus) for their mathematics requirements.

Aerospace Engineering and Mechanics

Aerospace engineering is a pioneering field which encompasses many areas of science and engineering, and plays a major role in the technological advancement of our society. The aerospace industry embraces not only the design and development of conventional aircraft and spacecraft, but also such areas as the development of suitable vehicles for high-speed ground transportation, the design of hydrofoil ships, and the design of deep-diving vessels for oceanographic research.

An aerospace engineer is in a professional field which is constantly changing and which involves a wide diversity of problems. For this reason the aerospace engineer must have a broad fundamental education in mathematics, the physical sciences, and the engineering sciences. The 4-year program leading to the bachelor of aerospace engineering and mechanics (B.A.E.M.) is designed to accomplish this objective. The required technical courses are designed to provide the student with a firm basic knowledge of engineering science, aerodynamics, mechanics, and dynamical systems. The elective part of the curriculum is extremely flexible, and allows the student to build on the fundamental work and to concentrate his study in some depth in an area of special interest. The available options are varied and permit students to prepare for careers in many different fields. For example, students could elect suitable options which would be appropriate for careers not only in basic aerospace engineering but also in fields such as oceanography, meteorology, environmental engineering, transportation systems, or noise reduction engineering.

The department offers an optional engineering intern program in the Upper Division. This program provides practical work experience in industry in alternate quarters (including summer) during the last 2 years. The program is run in conjunction with the intern program of the Department of Mechanical Engineering as a program of the School of Mechanical and Aerospace Engineering, and prospective candidates should contact the director of the program of the school for information.

The department is very actively involved in transportation studies, and students with an interest in the problems of urban and interurban transportation can participate in this special program. This program includes a carefully selected group of elective courses from various departments which prepare the student for some of the problems encountered in the transportation field, particularly in the application of new technologies to transportation.

Students interested in the problems arising from noise pollution and the possible solutions to these problems can select special courses in acoustics, offered by this and other departments, to form a coherent program with emphasis on acoustical engineering.

A recommended program for students majoring in aerospace engineering and mechanics is given below. The suggested form of the basic Lower Division program provides the necessary fundamental background for the more sophisticated Upper Division courses, and allows the student the greatest flexibility in arranging the Upper Division program.

LOWER DIVISION

	Credits
English Composition	8
Liberal Education Electives	10
Math 1211, 1221, 1231, 3211, 3221, 3231—Analysis	29
Phys 1271, 1281, 1291—General Physics	12
Phys 1275, 1285, 1295—Physics Laboratory	3
Chem 1014—General Principles	4
Phys 3501—Modern Physics	4
AEM 3036—Dynamics	4
EE 3000—Circuits	4
ME 3301—Thermodynamics	4
IT 1010—Introduction to Engineering	4
AEM 1001, 1005, 1006—Aerospace Engineering Orientation and Survey	3
CICS 1100—Introduction: Fortran Programming	2
Total Credits	91

UPPER DIVISION

	Credits
1. Liberal Education Electives	18
2. Required Technical Courses	42
AEM 5200, 5201—Fluid Mechanics I, II (8)	
AEM 5206—Lifting Surfaces (4)	
AEM 5515—Aerospace Structures I (4)	
AEM 3016—Deformable Body Mechanics (4)	
AEM 5430—Dynamical Systems I (4)	
ME 3305, 5342—Propulsion, Heat Transfer (8)	
AEM 5300—Flight Mechanics (4)	
AEM 5645, 5646—Laboratory I, II (6)	
3. Selected Required Technical Courses (select 3 of the 7 listed)	12
AEM 5202—Fluid Mechanics III (4)	
AEM 5438—Intermediate Dynamics (4)	
AEM 5330—Design I (4)	
EE 3001—Electrical Circuits II (4)	
EBB 3101—Ecology (4)	
Stat 3092—Statistics (4)	
AEM 5580—Mechanics of Elastic Solids (4)	
4. Technical Option	12
Technical elective courses to be selected from a coherent group of recommended courses for one of several options—see option program information in the departmental office.	
5. Electives	8
Total Credits	92

Agricultural Engineering

General—The opportunities for agricultural engineers have been increasing over the years and are expected to increase in the future. This is caused by a number of changing factors: the increase in the number of people employed in industries related to agriculture; the antedating of present solutions by the volatile nature of agricultural enterprises responding to economic pressures; and the realization that agricultural surpluses are minimal when faced with the increasing need for food world wide. Agricultural engineering talents have been used to solve both rural and urban problems by creating, by developing, and by applying new and improved processes, machines, and systems for utilizing and conserving our natural resources.

Curriculum—The agricultural engineering curriculum, in order to prepare for such a broad challenging field, normally can be completed in 4 years with a minimum 183 credits. A knowledge of the physical sciences including mathematics, physics, and chemistry is required of all engineers. In addition, biological and agricultural sciences form an important part of the agricultural engineer's program since he must consider the engineering aspects of biological systems. A broad background for implementation of systems in a challenging world is provided by 36 credits in communications, humanities, art, and social sciences.

Upon completion of the requirements, a bachelor of agricultural engineering degree (B.Ag.E.) is awarded by the Institute of Technology in cooperation with the Institute of Agriculture.

Each student, with the assistance of a faculty adviser, plans his curriculum to match his individual interests. The four specific technical areas which encompass agricultural engineering are: design of agricultural power and machinery, soil management and water control, building design and environmental control, food engineering and safety. In addition, students normally select courses from a number of other subjects to give them a broad background in such important topics as air pollution, waste management, and other environmental or quality concerns related to their interest.

An engineering intern program providing practical training and experience with an employer in addition to the formalized training is available to a limited number of students. Students may begin their work assignments in industry in the summer following either the first or the second year. Transfer students can be accommodated also in this program.

The Lower Division program provides the necessary background and maturity to enable the student to master the material offered in the Upper Division. It also provides a portion of the general education experience essential to an engineering education.

LOWER DIVISION

	Credits
English Composition or Communications	8
Math 1211, 1221, 1231, 3211 and 3221—Analysis I, II, III, IV; Linear Algebra and Differential Equations	25
Phys 1271, 1281, 1291—General Physics	12
Phys 1275, 1285, 1295—Physics Laboratory	3
Chem 1014—General Principles	4
CICS 1100—Introduction to Fortran Programming	2
EG 1025—Engineering Graphics	4
AgEn 1060—Agricultural Engineering Orientation	1
AgEn 1070—Introductory Agricultural Engineering	4
AEM 1015—Statics plus 2 of the following	12
AEM 3016—Deformable Body Mechanics (4)	
AEM 3036—Dynamics (4)	
ME 3031—Thermodynamics (4)	
CE 3400—Fluid Mechanics (4)	
EE 3000—Circuits (4)	
Liberal Education Electives	12
Natural Science Elective	4
Total Credits	91

Students may take Math 1311, 1321, 1331 (Computer Calculus) in place of Math 1211, 1221, 1231. Students interested in food engineering should consult adviser to select a chemistry sequence.

UPPER DIVISION

	Credits
1. Liberal Education Electives (as needed to complete 4-year Liberal Education requirement of 36 credits)	16±
2. Required Technical Courses	32
AEM 3016—Deformable Body Mechanics (4)	
AEM 3036—Dynamics (4)	
ME 3031—Thermodynamics (4)	
ME 5342—Heat Transfer (4)	
CE 3400—Fluid Mechanics (4)	
EE 3000—Circuits (4)	
(Two of above six courses normally are taken in Lower Division)	
AgEn 3050—Soil-Plant Relations (4) (see note following electives)	
AgEn 3060—Simulation and Evaluation (4)	
AgEn 5081, 5082, 5083, or 5084—Design: Interest Area (4)	
Engl 3085—Technical Writing (4) (or) Rhet 3551—Professional Writing (4)	
3. Selected Technical Courses	16
At least four of the following courses:	
AgEn 5060—Processing (4)	
AgEn 5070—Automatic Control and Instrumentation (4)	
AgEn 5130—Food Engineering I (4)	
AgEn 5140—Food Engineering II (4)	
AgEn 5330—Agricultural Machinery (4)	
AgEn 5340—Agricultural Tractors (4)	
AgEn 5540—Erosion Control, Watershed Engineering (4)	
AgEn 5550—Drainage and Irrigation Engineering (4)	
AgEn 5730—Agricultural Structures Design (4)	
AgEn 5740—Environmental Control for Agricultural Production (4)	
AgEn 5910—Agricultural Waste Management Engineering I (4)	
AgEn 5920—Agricultural Waste Management Engineering II (4)	
4. Agricultural and Biological Science Electives (may include AgEn 3050; see Note following Electives)	8
5. Electives	20
Total Credits	92
Minimum Graduation Requirements	183

Note—If AgEn 3050 is used in group 4, it must be replaced in group 2 with an additional agricultural engineering course from group 3.

The selected technical courses and electives are chosen from a group of recommended courses for one of several options—see sample programs in departmental office.

Architecture

(School of Architecture and Landscape Architecture)

The environment in which we live and work exerts enormous physical, emotional, and psychological influences on society. Unplanned and uncontrolled growth, visual chaos, pollution, and misuse of our natural and man-made resources have great impact on the way man lives. Many of the problems facing the world today are manifest in the physical expressions such as inadequate housing, antiquated transportation systems, polluted natural resources, sprawling, unplanned suburbs, and decaying urban areas.

Dramatic technological and scientific changes, enormous population and urban growth along with their social and economic adjustments are having a direct impact on the architectural and environmental design professions. The urgency and

critical nature of our rapidly changing world demands a far broader, more comprehensive approach to the education of architects, landscape architects, and environmental designers.

The greatest challenge is not so much the individual or isolated project as it is the blending of many varied factors into a sensitive and cohesive totality, a total fabric which will provide the background for a full and rich life in keeping with the innovative potentials of our times.

The places in which people live, work, and play are largely the product of our own devising. This process of divising, molding, and sloping the physical environment is the art and science of architecture. In its educational philosophy, the School of Architecture is concerned with the design of the total environment and the education of the total human.

In recent years, our society has become so diverse that even greater and wider scope of participation must be sought. The design and planning process demands that the architect be trained in a wide variety of skills and awareness as well as to be trained as a broadly based generalist with high professional competence and a liberal humanistic outlook.

The architecture program offers three undergraduate curricula:

Bachelor of Architecture Curriculum (B.Arch.) (5 years in Institute of Technology)—Normally requires 1 year of pre-architecture work followed by 4 years in the School of Architecture and Landscape Architecture. Required courses plus electives must equal at least 250 credits. This curriculum is intended for students who expect to enter the practice of architecture in any of its recognized phases. Upon completion, students may apply for admission to graduate study in architecture leading to the M.Arch. degree. When supplemented by practical experience the B.Arch. degree qualifies graduates for admission to registration examinations according to the laws of the various states.

Bachelor of Environmental Design Curriculum (B.E.D.) (4 years in Institute of Technology)—Normally requires 2 years of pre-environmental design work followed by 2 additional years in the School of Architecture and Landscape Architecture. Required courses plus approved electives must equal at least 190 credits.

This curriculum prepares students for (a) continuation toward the B.Arch. degree, (b) application for graduate study in architecture leading to the degree of M.Arch., or (c) multilateral transfer into other disciplines such as city design, city and regional planning, product design, or, in some cases, in the social or natural sciences.

Bachelor of Arts Curriculum (B.A. with major in Architecture) (4 years in College of Liberal Arts)—Normally requires 2 years of pre-architecture work followed by 2 years of work in the School of Architecture and Landscape Architecture. Required courses plus approved electives must equal 180 credits in the major.

Upon completion of the B.A. degree students may (a) transfer to the Institute of Technology and after 2 more years in the School of Architecture and Landscape Architecture earn the B.Arch. degree, or (b) may apply for admission to graduate study in architecture leading to the master of architecture degree.

This curriculum is intended for students who wish to combine the study of architecture with liberal education. It provides an advantageous approach to professional training in the fields of architecture, landscape architecture, urban design, urban and regional planning, and decorative, industrial, or interior design.

ADVANCED STUDY

Qualified students desiring to apply for admission to the University of Minnesota Graduate School for advanced study in architecture should consult the director of graduate studies in architecture and the dean of the Graduate School.

SPECIAL PROGRAMS

The School of Architecture and Landscape Architecture participates in the following special programs:

1. Combined Degree Programs in architecture, landscape architecture and planning.
2. MXC: Preliminary explorations in alternatives in experimental city design.
3. Computer Technology (in collaboration with the University Space Science Center): Students carry out research and development in computer technology and computer graphics as they might apply to architecture and landscape architecture and planning.
4. Community Advocacy Design (in collaboration with the University Education Center): Students work with urban and rural communities on a variety of design projects.
5. Built Environment Communication Center: A program employing various forms of audio-visual media for educational and documentary use. It is anticipated this program will be the nucleus of graphic and communication instruction and laboratory experience.
6. Foreign Study Program. Qualified students in the spring quarter of their third year of architecture and landscape architecture carry out their studies in various countries.
7. Educational Exchange Program with the School of Environmental Design, University of Lagos, Nigeria.

LOWER AND UPPER DIVISION

Architecture

The Lower Division program is common for all pre-architecture students and is 1 year in length. It provides the necessary background which prepares the student for the required courses in the School of Architecture and Landscape Architecture.

Lower Division (Pre-Architecture)

	Credits
Comp 1001-1002—Introductory Composition or Communications	8
Math 1211-1221-1231—Analysis I, II, III	15
Phys 1121-1122—Physics for Architects	10
Arch 1021-1022-1023—History of Environmental Development	12
Liberal Education Electives	4
Total Credits, Lower Division	49

After successful completion of the above work, the student must apply for admission to the School of Architecture and Landscape Architecture on form AR 110 before July 1 of the year for which admission is sought.

Upper Division (Architecture)

Arch 3081 through Arch 5123—Architectural Design	84
ArtS 1107-1108-1109-3140—Drawing and Painting	12
AEM 3092-3093—Statics and Mechanics of Materials	8
Arch 3061-3062-3064-3065—Architecture Technology	20
CE 3600-3601—Structural Design	8
Arch 5051 through Arch 5057—Architectural History (any three)	12
Arch 5115-Arch 5116—Structure and Form in Architecture	8
Arch 5137-5138—Planning	8
Arch 5126—Professional Practice	4
Recommended Professional Electives:	
Arch 3067—Integrated Design Systems	4
Arch 1001-1002-1003—Environmental Design	12
Liberal Education Electives	21
Total Credits, Upper Division	151
Total Credits Required for B.Arch. Degree	250

Environmental Design

The Lower Division curriculum provides fundamental courses which prepares the student for subsequent courses leading to the B.E.D. degree.

Lower Division

Comp 1001-1002—Introductory Composition or Communications	8
Math 1211-1221-1231—Analysis I, II, III	15
Phys 1211-122—Physics for Architects	10
Arch 1021-1022-1023—History of Environmental Development	12
Arch 1001-1002-1003—Environmental Design	12
ArtS 1107-1108-1109—Drawing and Painting	6
Arch 3061-3062—Building Systems	10
AEM 3092-3093—Statics and Mechanics of Materials	8
Liberal Education Electives	5
Total Credits, Lower Division	95

Upper Division

Arch 3081 through 3093—Architectural Design	36
ArtS 3140—Drawing and Painting	6
Arch 3067—Integrated Design Systems	4
CE 3600-3601—Structural Design	8
Arch 3064-3065—Architectural Technology	10
Arch 5051 through 5057—Architectural History (any three)	12
Liberal Education Electives	19
Total Credits, Upper Division	95
Total Credits Required for B.E.D. Degree	190

Astronomy

(School of Physics and Astronomy)

Students who wish to prepare for professional work in astronomy and astrophysics should enroll in the curriculum for the IT physics major and request an adviser from the Department of Astronomy. Information on astronomy and astrophysics options within the physics curriculum may be obtained either from the Astronomy Office, 450 Tate Laboratory of Physics, or the Undergraduate Physics Office in 148 Tate Laboratory of Physics.

Chemical Engineering

(Department of Chemical Engineering and Materials Science)

Chemical engineering is primarily an Upper Division program leading to the degree, bachelor of chemical engineering. Students entering the program should have the equivalent of 2 academic years of college study including 1½ years of college chemistry with laboratory, 1 year of college physics with laboratory, college mathematics through linear algebra and simple differential equations, and one course in the life sciences, as minimum preparation.

Chemical engineering is based on applications of chemistry, physics, mathematics, economics, and, occasionally, ecology as well as other aspects of biology. Devoted to a rapidly evolving industry, it requires knowledge of applied mathematics; material and energy balances; properties and physics of gases, liquids, and solid materials; fluid mechanics; heat and mass transfer; thermodynamics; reaction kinetics; process design, control, and optimization. Because of an emphasis on basic and engineering sciences, a chemical engineer is most nearly the universal engineer. He is particularly well suited to engage in a very wide variety of new and old industries and activities, in research on new products and ideas, in development of new processes, in manufacturing, or in marketing. Chemical engineering deals in particular with the unit operations such as materials handling, mixing, fluid flow and metering, heat exchange, filtration, drying, evaporation, distillation, absorption, extraction, crystallization, ion exchange, and processing in chemical reactors. These operators are vital in making an industry based on a chemical or physical transformation a commercial success. A chemist makes qualitative use of these operations in the laboratory; but to apply them to a larger-scale industrial process, the chemical engineer must have a complete and quantitative understanding of the engineering as well as the scientific principles on which the operations are based. The chemical engineer is primarily a producer, and it is his special province to develop a process from its laboratory beginnings, through semiworks equipment, to the full-scale production stage.

Because many industries are based on some chemical or physical process involving the transformation of matter, the chemical engineer is much in demand. He may be engaged in the manufacture of inorganic products—acids, alkalies, ammonia, paint pigments, fertilizers; in the organic industries—dyes, explosives, textiles, polymer fibers, rubber, rocket fuels, solvents, plastics, agricultural chemicals, pharmaceuticals, petroleum products; in the manufacture of graphite, calcium carbide, abrasives, wet and dry batteries, fuel cells, electroplating; in the metallurgical industries; in the food processing industries; and in the fermentation industry for production of chemicals such as antibiotics and feed supplements. Many other products such as fuel gas, gasoline, oil, nuclear materials, paper, glass, ceramics, and cement concern the chemical engineer, as do many problems of waste disposal and environmental protection.

In industry chemical engineers do basic and applied research, development work, design and modifications of processes and equipment, and plant operation. Some enter sales engineering, marketing, and management.

The chemical engineer may also enter into the field of nuclear engineering which encompasses processing, separation, development, and testing of materials for nuclear reactors; design and operation of nuclear reactors for research, isotope production, nuclear fuel breeding, heat and power generation; and utilization as well as storage of radionuclides and fission products. He may also enter the field

of bioengineering. This involves the application of engineering methods and principles to biological problems ranging from the utilization of the activities of microorganisms to the design of prosthetic devices and artificial human organs. Because of the breadth and flexibility of the chemical engineering curriculum it is chosen by some students who plan postgraduate study in medical sciences, business administration, or patent law.

On the Twin Cities Campus the first 2 years of the normal curriculum are the same as the Lower Division curriculum in chemistry, except that an ecology course and a biology course are included. The first 2 years differ from the Lower Division curriculum in engineering, because chemical engineering requires a great deal more study of chemistry than do the other branches of engineering.

NORMAL PRE-CHEMICAL ENGINEERING PROGRAM ON TWIN CITIES CAMPUS

LOWER DIVISION

First Year	Credits—f,w,s		
Chem 1031, 1032, 1034—General Principles I, II, Synthesis I	5	5	5
Math 1311, 1321, 1331—Computer Calculus I, II, III (or) Math 1211, 1221, 1231—Analysis I, II, III	5	5	5
Comp 1001, 1002—Introductory Composition	4	4	..
Electives (may be rearranged with Engl 1001, 1002)	..	0-4	4-8
Second Year			
Chem 3034, 3201, 5126—Synthesis II, Rates and Mechanisms, Modern Analytical Chemistry	5	5	5
Phys 1271, 1281, 1291—Mechanics, Heat and Electricity, Magnetism and Optics	4	4	4
Phys 1275, 1285, 1295—General Physics Laboratory	1	1	1
Math 3211, 3221—Analysis IV, Linear Algebra and Differential Equations	5	5	..
AEM 3016—Deformable Body Mechanics (or) EE 3000—Electrical Circuits (or) Math 3231—Vector Analysis	..	..	4
EBB 3101—Ecology for Engineers and Physical Scientists	..	4	..
GCB 3201—Molecular Biology (or approved biology alternatives)	..	..	3-4
Elective (may be rearranged with EBB 3101)	0-4	..	..

REQUIREMENTS FOR THE BACCALAUREATE DEGREE

1. Completion of the Lower Division requirements, as exemplified by the numbered courses in the normal pre-chemical engineering program shown above. A different program may still satisfy the requirements, as in the case of a student who transfers from another curriculum or another institution. From 96 to 105 credits in Lower Division represent normal progress toward the B.Ch.E.

Transfer Students—Students intending to transfer from another campus or school should take the most nearly equivalent courses available to them. If they have questions they are encouraged to write or visit the Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis, Minnesota 55455. When they transfer, students can obtain certification of completion of the Lower Division requirements through the regular admissions procedure.

2. Completion of the Institute of Technology Minimum Liberal Education Requirement, which is described on pages 60 and 61. That requirement totals 36

credits, of which 8 are Freshman English or substitutes, and 7 or 8 are EBB 3101 and GCB 3201 or substitutes. Of the remainder, at least 12 credits must be in Category 3, "Man and Society," and at least 8 credits must be in Category 4, "Artistic Expression." Thus, of all the free elective credits in the Lower Division and Upper Division programs in chemical engineering shown here, 20 or 21 should be devoted to completing the Liberal Education requirement.

3. Completion of a coherent Upper Division program of scientific and technical courses. A student in conjunction with his adviser designs his program in two stages: a 1-year plan for the third year must be filed by the beginning of that year; and ordinarily by the beginning of the fourth year a complete 4-year program must be submitted for certification by the department. The student then receives his degree upon completing all courses in his program with a GPA of 2.00 or better. His program must total at least 191 quarter credits, the minimum required for the B.Ch.E. Normal 4-year programs would involve about 200 credits.

The following is a basic Upper Division program. By selecting technical electives and, in certain cases, substituting courses with approval of adviser and department, a student can emphasize chemistry, mathematics, ecology, biochemical engineering, biomedical engineering, nuclear engineering, metallurgical engineering, polymer engineering, materials science, business administration, or another special interest. Coherent programs which illustrate these possibilities are available from the departmental office, 151 Chemical Engineering Building. Advisers and the department's director of undergraduate studies can be contacted through the same office.

BASIC PROGRAM IN CHEMICAL ENGINEERING

UPPER DIVISION

Third Year

	Credits—f,w,s		
ChEn 5101, 5102, 5103—Principles: Stoichiometry and Balances, Fluid Mechanics, Heat and Mass Transfer	4	4	4
ChEn 5001—Mathematical Methods in Chemical Engineering and Materials Science	2	..	..
ChEn 5401—Chemical Engineering Laboratory	..	..	2
Chem 5505—Statistical Thermodynamics	4	..	..
ChEn 5201—Thermodynamics and Materials States	..	4	..
ChEn 5202—Chemical Engineering Thermodynamics and Kinetics	..	..	4
MatS 5011—Introduction to Science of Materials	4	..	..
Phys 3501, 3505—Modern Physics and Laboratory (or) Chem 5502—Quantum Mechanics with Laboratory	..	5	..
Electives	0-4	3-5	4-8

Fourth Year

ChEn 5104—Separation Processes	4	..	..
ChEn 5501, 5502—Process Evaluation and Design	..	4	2
ChEn 5301—Chemical Reactor Analysis	4	..	..
ChEn 5601—Process Control	..	4	..
ChEn 5402, 5403—Chemical Engineering Laboratory	2	2	..
Technical Electives	3-4	3-4	6-8
Electives	3-4	3-4	6-8

Students interested in bioengineering should contact Professor Tsuchiya in fall quarter of third year in order to reserve places in Biol 3021, 3025 for winter or

spring quarter. Enrollment in these courses as in some other biology courses is severely limited.

Descriptions of chemical engineering courses begin on page 77.

Chemistry

Traditional chemistry curricula are compartmentalized into the divisions of general, analytical, organic, and physical chemistry. These divisions do not reflect the integrated application of chemistry to the problems of industry, medicine, and agriculture. Thus, all chemistry majors enrolled in traditional curricula take essentially the same courses regardless of interests. Clearly it is impossible in 4 years to educate adequately a student in the varied ways that chemistry makes its impact on our modern age. Consequently, the Department of Chemistry provides a multitrack program leading to the Bachelor's degree. These tracks allow a student after the first quarter of the third year to develop expertise in those areas of chemistry which interest him most.

Minnesota begins with a set of courses called the "core program in chemistry" which contains the knowledge prerequisite to a successful study of the diverse, higher-level courses to be taken later in the various tracks which lead to the Bachelor's degree. The first 7 quarters constitute the core program: *two* courses on general principles of chemistry with analytical laboratory work, *two* courses which examine the syntheses and chemical properties of compounds, *one* course on rates and mechanisms of chemical reactions, *one* course on modern analytical chemistry, and *one* course on statistical thermodynamics. These courses are taken by the student in the order given above. The philosophy behind the content of these core courses is to eliminate artificial boundaries between the various areas of chemistry and to properly present chemistry as an interrelated whole.

Following completion of this "core program" a student will be at liberty to choose from any one of the several "tracks" shown below that sequence course most suited to his interests and professional goals.

The Department of Chemistry's program is not easily divided into strict lower and upper divisions. The student must complete seven quarters of required "core" chemistry courses, after which time he chooses a "track" best suited to his needs and interests in consultation with his adviser. This "track" can contain courses from several different departments as long as they form a cohesive program with a specific aim. A minimum of 180 credits are required for graduation.

"CORE" PROGRAM

	Credits
English Composition or Communications	8
Math 1311-1321-1331-3211-3221—Computer Calculus I, II, III, Analysis IV, Introduction to Linear Algebra and Linear Differential Equations	25
Phys 1271-1281-1291—General Physics	12
Phys 1975-1985-1995—General Physics Laboratory	3
Chemistry Core Courses:	
Chem 1031, 1032—General Principles I and II	10
Chem 1034, 3034—Synthesis I and II	10
Chem 3201—Rates and Mechanisms	5
Chem 5126—Modern Analytical Chemistry	5
Chem 5505—Statistical Thermodynamics	4
Liberal Education Electives (8 cr of German count in this total)	36
Ger 1101-1102-1103—Beginning German	15
Total Credits	132

"TRACK" PROGRAMS

Basic Track: Chem 5502, 5703, plus 11 credits of elective Upper Division chemistry courses chosen in consultation with the student's major adviser.

Biophysical Chemistry Track: Chem 5522, 5523, 5524 plus at least 12 credits chosen in consultation with the student's adviser.
5746; Chem 5342, 5580, 5125; MicB 3103; ChEn 5751, 5752, 5753; GCB 3012, 5082; BPhy 5156, 5157.

Chemical Instrumentation Track: Chem 5127, 5128, plus at least 10 credits chosen in consultation with the student's adviser.

Materials Science Track: 20 credits of appropriate courses in solid state chemistry and materials science chosen in consultation with adviser.

Eco-Chemistry Track: Chem 5310, 5704 (chemistry of the atmosphere), plus at least 12 credits chosen in consultation with the student's major adviser.

Open Track: At least 20 credits of Upper Division courses chosen in consultation with the student's major adviser.

The basic track is recommended for those students planning to attend graduate school in chemistry. The open track provides an avenue for individual students to innovate and formulate special programs tailor-made for their special educational goals. In all cases, these special programs will have to be approved on an individual basis by the director of undergraduate studies. The other tracks allow the student to specialize in areas closely related to chemistry at the undergraduate level.

Civil Engineering

(Department of Civil and Mineral Engineering)

Thoughtful and ambitious high school students have differing aspirations for the development of their talents. Many seek careers that will involve them in meeting the changes in society brought about by innovations in science and technology. They also seek careers that will provide a significant measure of service to others. These students find a strong appeal in civil engineering because of the wide range of outlets for energies and talents that are to be found within this profession.

Civil engineering probably can be characterized best by its function of making the world a more habitable place for mankind. Civil engineers serve the public as planners, designers, and supervisors of transportation systems, structures, pollution control facilities, water resource projects, and other essential creations of our civilization. Although civil engineers are needed to develop areas where power building and transportation complexes are essential for growth, they are needed even more in a well-developed urban society. Population concentrations create new problems in all areas of civil engineering. The civil engineer, in the future as in the past, will, therefore, play an important role in adapting the environment for the health and general benefit of man. This requires the highest order of technological competence. An understanding of government structure and social goals also is necessary so that the engineer can work effectively with men and women of nontechnical background.

The need for well-educated civil engineers is great, and there are ample opportunities in both private practice and public service. Graduates may enter careers in design, construction, maintenance, management, or research and development. Many find employment in federal, state, and municipal engineering work;

in private and public utility enterprises; in the construction industry; and in aiding the modernization of distant lands.

Principal fields of specialization within civil engineering are: environmental engineering; water resources engineering; transportation engineering; structural engineering; soil mechanics and geo-engineering; construction materials; and land use planning (including surveying and mapping).

The curriculum leading to the bachelor of civil engineering degree (B.C.E.) prepares men and women to enter this profession. This 4-year program requires a minimum of 184 credits (or equivalent demonstrated competence) for graduation.

SPECIAL PROGRAMS IN CIVIL AND MINERAL ENGINEERING

The following three interdisciplinary programs of current national interest are offered as an ongoing part of civil engineering:

Environmental Engineering—The systematic control of air, water, and land pollution to protect the public health and enhance environmental quality by providing for: safe and adequate water supplies; treatment and disposal of wastewater; and solid waste management systems.

Transportation Engineering—The economics, planning, designing, construction, maintenance, and administration of highways, railroads, airways, pipelines, and transmission lines for the conveyance of passengers, materials, or energy.

Water Resources Engineering—The application of hydrology, meteorology, fluid mechanics, and other basic knowledge in the design and operation of water resources systems; irrigation and drainage; hydropower development; flood control; coastal engineering and harbor development for a more effective and humane utilization of our water resources. (The St. Anthony Falls Hydraulic Laboratory, where many types of water resources research are under way, is a part of the Department of Civil and Mineral Engineering.)

An engineering intern program is available for civil engineering students after completion of approximately 5 quarters of study. Participants in the program will complete a total of 11 quarters of academic study and earn credit for approximately ½ quarter through two 6-month work periods included in their program.

DEGREE PROGRAM IN CIVIL ENGINEERING

General Program Description—In the first 2 years of study, when the student is apt to be undecided as to his professional objectives, the requirements of the civil engineering program are only of a general nature. This is essential so that:

1. Students may transfer from one branch of engineering to another without loss of time, and
2. Students may enter the third and fourth years of professional training in civil engineering by transfer from a liberal arts college or a junior college.

The third and fourth years of study are intended to provide training in engineering science and engineering practice.

The total requirements of the program leave ample room for the development

of a strong "minor" area of study such as business administration or for the attainment of legitimate specialized professional objectives. This is accomplished through coherent elective credits.

General Requirements:	Credits
Mathematics	
Calculus and analytic geometry	15
Linear algebra and linear differential equations	5
Advanced calculus (or) probability, statistics, and linear programming	4
Basic Science	
Physics (with laboratory); dynamics; heat, electricity, optics	15
Chemistry (with laboratory)	10
Elective chosen from geology, biology, ecology, chemistry, or physics	0-8
Engineering Science	
Statics	4
Fluid mechanics (with laboratory)	4
Introduction to structural analysis	4
Computer programming	4
Approved engineering science electives	8-16
Introduction to engineering in society and to graphical communication	4-6
Engineering Analysis, Design and Systems	
Minimum of five introductory courses from the seven professional areas; soil mechanics, structures, environmental engineering, water resource engineering, transportation, materials and surveying	20
Completion of an 8-credit sequence in three of the professional areas listed above (if all seven introductory courses are included in the program only two of the 8-credit sequences need be completed)	24
English Composition, Humanities, and Social Science (required and elective courses)	36
Elective Program	
Must be chosen so as to form part of a coherent program	18
Total Credits	184

Example Programs—Example programs in environmental engineering and transportation engineering are given below. Programs in other areas of specialization in civil engineering may be obtained by writing the Director of Undergraduate Studies, Department of Civil and Mineral Engineering, 112 Mines and Metallurgy Building, University of Minnesota, Minneapolis, Minnesota 55455.

ENVIRONMENTAL ENGINEERING—SAMPLE PROGRAM

Lower Division

(93 Credits)	Credits
English Composition or Communications	8
Math 1211, 1221, 1231, 3221, and CE 3010—Analysis I, II, III, Introduction to Linear Algebra and Linear Differential Equations, Data Analysis and Optimization in Civil Engineering	24
CICS 3101—A Fortran Introduction to Computer Programming	4
Phys 1271, 1275, 1281, 1285, 1291, 1295—General Physics (with laboratory)	15
Chem 1004, 1005—General Principles of Chemistry	10
AEM 1015—Statics	4
I of T 1010—Introduction to Engineering	4
CE 1001—Civil Engineering Orientation	1
CE 3400—Fluid Mechanics	4
CE 3605—Introduction to Structural Analysis	4
Geog 1301 and Soc 1505 (or LA 1031 or Pol 1001)	10
Biol 1011—General Biology	5

Upper Division

(92 credits minimum)

Liberal Education Electives (see department for recommended list) 18
Recommended Civil Engineering Courses:
CE 3200, 3500, 5500, 5501, 5505, 5510, 5401, 5405, 5420, 5210, 5201, 5600, 3700 (for course titles and descriptions, see Section IV) 53

Optional Technical Courses

(20 credits minimum) Credits

EBB 5027—Human Population, Environment, Resources 4
Chem 3301, 3302—Elementary Organic Chemistry .....(each) 5
Geo 5601—Limnology 3
Biol 3013—Microbiology 4
ME 3301—Thermodynamics 4
PubH 5181—Introduction to the Air Pollution Problem 3
PubH 5151—Environmental Health 4
ChE 5101, 5103—Principles of Chemical Engineering .....(each) 4

TRANSPORTATION ENGINEERING—SAMPLE PROGRAM

Lower Division

Same as environmental engineering program, except substitute Ecol 3101 for Biol 1011.

Upper Division

Liberal Education Electives (see department for recommended list) 18
Recommended Civil Engineering Courses:
CE 3100, 3102, 5100, 3200, 5200, 5201, 5202, 5210, 3300, 5304, 5401, 5600, 3700 (for course titles and descriptions, see Section IV) 53

Optional Technical Courses

(21 credits minimum) Credits

Arch 5137, 5138—Planning: Urban Function, Structure, and Planning: Theory, Methodology .....(each) 4
IEOR 5000, 5040—Intro: Industrial Engineering Analysis, and Intro: Operations Research .....(each) 4
I of T 5411, 5412, 5413—New Concepts: Urban Transportation .....(each) 4
EE 3460 (for CE)—Special Investigations 4
Geo 1111—Introductory Physical Geology 5
Tran 3054—Fundamentals of Transportation 4
Tran 5195—Government Economic Regulation: Transportation 4
Geog 5383—Transportation Geography 4

Computer, Information, and Control Sciences

Computer science is concerned with the study of the hardware and software (programming) aspects of high-speed computing devices and with the applications of these devices to the solving of a broad spectrum of technological and business problems. Bachelor's degree training in computer science can be obtained in either the College of Liberal Arts (CLA) or the Institute of Technology (IT). Details of the former program can be found in the CLA bulletin. Both curricula are designed to give the student a broad base in the foundation subjects of computer science. By means of the Upper Division Option and a choice of alternatives in the required courses, the curriculum is made flexible enough so that a student can

build on the basic foundation with a concentration within computer science or in outside (or interdisciplinary) areas involving the applications of computers. This should prepare the student for a variety of industrial and governmental positions involving computer usage, as well as give the student the background necessary for pursuing graduate work.

The 4-year IT curriculum leads to the degree of bachelor of computer science, B.Comp.Sci.

In addition to the required courses, a student must satisfy the Liberal Education Requirement for the Institute of Technology and have sufficient approved electives to complete a minimum of 180 credits for graduation.

All IT courses in the required program as well as the 28 credits which constitute the Upper Division Option must be taken on an A-N basis (unless particular courses are offered only on an S-N basis).

Transfer Students—A student with a calculus, elementary physics, and FORTRAN background will be able to enter the program as a junior, assuming that his liberal education courses are roughly equivalent to those required by the Institute of Technology. Most transfer students will not have had the material covered in CICS 1106 and 3107; however, a program can be worked out in which those courses are taken during the junior year or summer term. All transfer students should go to the departmental office for advice.

Specialized information on service courses and programs is available from the Office of Computer, Information, and Control Sciences in 114 Main Engineering Building.

LOWER DIVISION

	Credits
English Composition or Communications	8
Math 1311, 1321, 1331—Computer Calculus I, II, III	15
Math 3211, 3221—Analysis IV; Linear Algebra and Differential Equations	10
Stat 3091 or 5121—Probability and Statistics	4
Phys 1271, 1281, 1291—General Physics	12
Phys 1275, 1285, 1295—Physics Laboratory	3
CICS 1100—Introduction to FORTRAN Programming I (optional 2 credits; intended for people without previous programming experience)	
CICS 1105-1106—Fundamentals of Algorithms and Languages I-II	8
CICS 3001—Perspectives on Computers and Society	4
CICS 3107—Introduction to Assembly Language Programming	4
Liberal Education Electives	20
Total Minimum Lower Division Credits	90

UPPER DIVISION

	Credits
Engl 3085—Technical Writing	4
Liberal Education Electives	16
Free Electives	16
Required Technical Courses:	
At least one Upper Division mathematics or statistics course (recommend Math 5701, Combinatorics)	4
CICS 5102—Structure and Programming of Software Systems II	4
CICS 5121—Introduction to Data Structures	4
CICS 5201—Computer Engineering	4
CICS 5301—Numerical Analysis	4
CICS 5400—Introduction to Automata Theory	4
CICS 5501—Artificial Intelligence and Heuristic Programming	4

Upper Division Option:

Elective courses which form a coherent program in CICS and application areas; for example, health sciences computing, transportation systems, environmental engineering, machine design, software systems, mathematics of computation, theory of computation, etc. These courses are to be selected from additional 5000-level CICS courses and adviser-approved courses from other departments. See option program information available in departmental office 28

Total Minimum Upper Division Credits 92

Electrical Engineering

Many of today's electrical engineers encounter assignments in fields that developed after their formal education was completed, e.g., integrated circuits, computer technology, solid-state electron devices, and the simulation and design of large-scale engineering systems. Indeed, some electrical engineers find themselves applying their expertise in these new areas to problems that are far afield from the traditional boundaries of electrical engineering; examples include the urban economic system, transportation, computer-aided education, and monitoring systems for hospital patients. The appearance of new technologies from the results of basic scientific research will surely continue as well as the search for technological solutions to the countless complex problems that arise from the concentration of population in urban centers, and from the need to conserve vital resources and the physical environment. In the face of such a challenge, the electrical engineering curriculum seeks to prepare its graduates to cope with their first assignments, but probably more importantly, to provide a fundamental background for continued professional development.

The required curriculum provides essential scientific and engineering background; elective freedom, primarily in the senior year, allows for some concentration in specialized areas or in related interdisciplinary studies. The available senior elective courses within electrical engineering range from biomedical instrumentation to computer engineering, control or communication systems, power and electromechanics, microwave applications, and electronic devices and circuits. Supporting courses from other areas are broadly available.

An honors program is also offered within the Department of Electrical Engineering, and a cooperative, work-study program is being established which will offer a measure of industrial experience through alternate quarters on campus and on industrial assignment during the last 2 years of the curriculum.

The 4-year curriculum includes a minimum of 192 quarter credits and leads to the degree of bachelor of electrical engineering (B.E.E.). *Curricular details and sample 4-year program plans leading to the B.E.E. degree at the University of Minnesota can be obtained by writing to the Department of Electrical Engineering, University of Minnesota, Minneapolis, Minnesota 55455.*

LOWER DIVISION

	Credits
English Composition or Communications	8
Math 1211-1221-1231, 3211, 3221, 3231—Analysis I-IV, Introduction to Linear Algebra and Differential Equations, Vector Analysis	29
Phys 1271-1281-1291—General Physics	12
Phys 1275-1285-1295—Physics Laboratory	3
Chem 1014—General Principles	4
CICS 1100-1101—Introduction to FORTRAN Programming	4

EE 1000—Introduction to Electrical Engineering	1
EE 1510—Elements of Electrical Engineering	5
Engineering Science Elective (AEM 3036 or ME 3301 or Stat 3092 recommended)	4
Liberal Education Electives	10
Natural Science Elective (Chem 1032 or Phys 3501 recommended)	4
Electives	10
Total Credits	93

UPPER DIVISION

The requirements listed below apply to the graduating class of 1974. Students who will be graduated in 1975 or later are referred to the Department of Electrical Engineering office for Upper Division requirements. Sample programs, details about the options in electrical engineering, and information about the special requirements of the honors program are given in the EE Curriculum Guide, available in the departmental office.

	Credits
Required Technical Courses	
EE 3050-3051—Electronics I-II	8
EE 3100-3101—Electromagnetic Fields I-II	8
EE 3400-3401-3402—Junior EE Laboratory	6
EE 5000-5001—Linear Systems Analysis	8
EE 5050—Nonlinear Electronic Circuits	4
Engl 3085—Technical Writing	3
Math 3061—Operational Methods for Linear Systems	4
EE 5050—Electronic Circuits Laboratory (or) EE 5101—Electromagnetic Fields Laboratory (or) EE 5301—Electromechanics Laboratory	1
	42
Technical Option	32
Electives (including Liberal Education courses to satisfy the CLE requirements in IT)	25
Total Credits	99

Geo-Engineering

(Department of Civil and Mineral Engineering)

Geo-engineering consists of the application of engineering and geological principles to the problems of analysis and design in those engineering activities directly related to the earth, its material structure, forces, and economic products.

The curriculum provides training in engineering geology and related topics such as rock mechanics and has sufficient flexibility so that the student can obtain a limited degree of specialization in one of the fields with which geo-engineers are concerned. It also allows able and interested students to prepare for graduate study in one of the numerous areas of specialization within geo-engineering.

Geo-engineers carry on their professional work in many branches of industry and government including:

The construction industry, involving problems of the behavior of rocks and soils such as dam site studies and selection, foundations, slope stability and design, erosion control, drainage, irrigation, highway subgrades, tunneling and underground excavation, and many others.

The mineral industries, including metal mining, petroleum, and industrial raw materials where the major concerns are analysis and design in the exploration and development of mineral resources. This will include problems in mineral economics, mineral valuations, application of geochemical, geo-

physical, and geologic principles and techniques. The geo-engineer may also advise and assist mining engineers on problems of ore reserves, quality control, the effects of geologic factors on rock behavior, and many others.

Government bureaus and other agencies involved in environmental studies, geothermal energy, water resources, underground transit systems, etc.

Depending upon his interests the geological engineer may work for mining or petroleum companies, consulting engineering groups, construction companies, research organizations, or government agencies. It should be realized that a high degree of specialization within the broader professional field usually requires some postgraduate study.

A 4-year degree program is offered that leads to the degree of bachelor of geo-engineering (B.Geo.E.). A minimum of 184 credits (or equivalent demonstrated competence), including field trips, is required for graduation.

LOWER DIVISION

The following is a recommended program which can be modified, in consultation with a faculty adviser, to better meet individual student interests.

	Credits
English Composition or Communications	8
Math 1211, 1221, 1231; 3221; *and* CE 3010 (or) ME 3900—Analysis I, II, III; Introduction to Linear Algebra and Differential Equations; Data Analysis and Optimization; Introduction to Engineering Statistics	24
Chem 1004, 1005, 1006—General and Solution Chemistry	14
Phys 1271, 1275, 1281, 1285, 1291, 1295—General Physics with Laboratory	15
I of T 1010 (or) EG 1025—Introduction to Engineering (or) Engineering Graphics	4
I of T 1003, 1004—Seminar: Freshman Engineers	2
AEM 1015—Statics	4
CE 3400—Fluid Mechanics	4
CICS 1100—Introduction to FORTRAN Programming I	2
AEM 3016 or AEM 3017—Deformable Body Mechanics	4
Electives	10

UPPER DIVISION

Junior Year—All Options

	Credits
MinE 5611—Mineral Resources I: Exploration and Development	4
MinE 5612—Mineral Resources II: Development and Production Systems	4
MinE 5613—Mineral Resources III: Examination and Valuation of Mineral Property	4
Geo 1111—Introductory Physical Geology	5
Geo 3401—Introductory Mineralogy	5
Geo 3103—Structural Geology	5
CE 3300—Elements of Soil Mechanics	4
GeoE 5216—Geo-Engineering and Rock Mechanics I	4
GeoE 5330—Geo-Engineering and Rock Mechanics II	4
CE 3100—Surveying	4
Electives (CLA)	7

Senior Year—Rock Mechanics Option

	Credits
GeoE 5334—Rock Mechanics III	4
GeoE 5437—Computer Applications in Geo- and Mineral Engineering	4
GeoE 5260, 5262—Geo-Engineering Analysis	5
GeoE 3012—Geo-Engineering and Mine Surveying	2
Geo 5512—Principles of Seismic Exploration	3
Geo 5513—Principles of Electrical Exploration	3

MinE 5825—Metallurgical Heat Transfer and Fluid Flow (or) CE 3400—Fluid Mechanics	4
MinE 5700—Systems Analysis for Mineral Engineering	4
Technical Electives (geology or geo-engineering or mineral engineering)	7
Electives (CLA)	12
Geology Summer Field Trip (4 weeks or more)	

Senior Year—Exploration Option

	Credits
GeoE 5437—Computer Applications in Geo- and Mineral Engineering	4
GeoE 5260, 5262—Geo-Engineering Analysis	5
GeoE 5180—Geochemical Exploration	3
Geo 5512—Principles of Seismic Exploration	3
Geo 5513—Principles of Electrical Exploration	3
Geo 5351—Metal Sulphide Deposits	5
Geo 5451—Optical Mineralogy and Petrography	4
MinE 5830—Microscopy for Mineral Engineering	3
MinE 5800—Introduction to Mineral and Metal Extraction	4
Electives	12
Geology Summer Field Trip (4 weeks or more)	

Geology and Geophysics

The Department of Geology and Geophysics offers three programs in the undergraduate curriculum: (a) Geology option A—General Geology; (b) Geology option B—Mineralogy and Petrology; (c) Geophysics. A minimum of 189 credits is required for graduation with the degree of B.S. Geol., for options A and B, or B.S. Geophys. for the geophysics option.

Geologists and geophysicists are employed in a wide variety of fields. These include exploration for and development of natural resources such as petroleum, minerals, and groundwater. They also include urban planning, conservation, oceanography, and various branches of civil engineering. Potential employers are private industry, research institutions, universities, and many governmental agencies. An advanced degree is generally necessary for employment at a professional level in research and development work or in teaching.

The undergraduate curriculum is designed to provide a strong foundation in physics, mathematics, chemistry, and (for option A) biology. Geophysics emphasizes the first two. Some students may select a geology or geophysics major simply to obtain this broad science base.

The geology portion of the curriculum is built around a core of seven basic courses taken during the second and third years. Selection of an option should be made during the second year, although later transfers are possible. All options will accommodate either students preparing for graduate work or planning to terminate with a B.S.

Geophysics is the study of the physical structure and properties of the earth. The curriculum includes seismology applied to earthquakes and to petroleum exploration; gravity applied to internal structure and to mineral exploration; magnetic, thermal, and electrical properties applied to topics ranging from continental drift to mineral exploration.

GENERAL REQUIREMENTS

All Options

	Credits
Liberal Education Courses (CLE)	39
Mathematics (Math 1211, 1221, 1231, 3211, 3221)	25
Physics (Phys 1271, 1281, 1291, 1275, 1285, 1295)	15
Core Geology	39
Second year—Geo 1111(5f), 3401(5w), 3102(5s)	
Third year—Geo 3101(5f), 3112(5w), 3103(5s)	
Summer Field Course—Geo 5110 (9 su)	
Total Credits	118

LOWER DIVISION

All Options

	Credits
Liberal Education Courses, including English (meeting Council on Liberal Education and IT specifications)	20
Mathematics	25
Physics	15
Chemistry	8-10
Sophomore Geology Sequence: Geo 1111f, 3401w, 3102s	15
Additional chemistry, physics, biology, or mathematics as specified under option requirements	5-7
Total Credits	90

UPPER DIVISION

All Options

	Credits
Liberal Education Courses (meeting Council on Liberal Education and IT specifications)	19
Junior Geology Sequence: Geo 3101f, 3112w, 3103s	15
Summer Field Course: Geo 5110	9
Completion of option requirements (geology and basic science and math)	34-36
Free Electives	20-22
Total Credits	99

SPECIAL REQUIREMENTS

Geology Option A—General Geology

In this option the historical and dimensional aspects of geology are emphasized, including the record and evolution of animal and plant life, the succession and genesis of rocks in the earth's crust, rock-deforming processes and events, and the origin of landforms. The background science requirement in this option is a balanced knowledge of chemistry, physics, mathematics, and biology.

	Credits
Chemistry (Chem 1004, 1005, plus either Chem 3301, 3302 [or] Chem 5520-5521 *and* CE 3400)	20
Biology (Biol 1011 plus two additional courses)	14
Additional credits in geology selected from 5102, 5151, 5251, 5261, 5505, 5506, 5507, 5601, 5611, 5642, 5652	15
Free Electives	22
Total Credits	71

Geology Option B—Mineralogy and Petrology

In this option the chemical and physiochemical aspects of geology are emphasized, including the structure and composition of minerals, the study of rocks as

chemical systems, the distribution and migration of elements, and the deposition of minerals and rocks from solutions and melts. The background science requirement of this option emphasizes chemistry and physical chemistry, with additional physics and mathematics.

	Credits
Chemistry (Chem 1004, 1005, 1006, 5520-5521, 5510, 5511)	23
One additional course in mathematics or computer, information, and control sciences sequence (normally Math 3231 or CICS 1101-1102-1103)	4-5
Physics (Phys 3501 plus one additional course in physics)	8-9
Additional credits in geology and geophysics selected from Geo 5301, 5302, 5351, 5401, 5452, 5505, 5506, 5507	15
Free Electives	20
Total Credits	71

Geophysics

In this option, emphasis is placed on obtaining a sound basis in geology, physics, and mathematics, with additional course work in geophysics, electronics, electromagnetism, chemistry, and computer science.

	Credits
Chemistry (Chem 1004, 1005)	10
Additional credits in physics (Phys 3501, 3515, 3011)	9
Geophysics selected from Geo 5505, 5506, 5507, 5511, 5512, 5513	9-12
Geology, mathematics, physics, electrical engineering, chemistry or computer science selected from:	20-23
Geo 3099, 5102, 5108, 5251, 5255, 5301, 5302, 5351, 5611, 5642	
Math 3231, 3142, 5512, 5457-5458-5459, 5601-5602-5603	
Stat 3092 or 5131	
Phys 3012, 5011-5012-5013 or 5021-5022; 5023-5024-5025; 5851	
EE 3100, 3101 may be substituted for Phys 5023-5024-5025; 1500-1501 may be substituted for Phys 5851	
Chem 5520-5521	
CICS 1001-1102	
Free Electives	20
Total Credits	71

Industrial Engineering/Operations Research

(Department of Mechanical Engineering)

Professional training in industrial engineering is offered through an industrial engineering option in mechanical engineering.

Industrial engineering is concerned with the design, improvement, and installation of integrated systems of men, materials, and equipment. It draws upon specialized knowledge and skills in the mathematical, physical, and social sciences together with the principles and methods of engineering analysis and design to specify, predict, and evaluate the results to be obtained from such systems. The industrial engineer studies product designs to adapt them for production, determines an optimal system of necessary operations, selects the most economical production equipment and tooling, and develops effective work methods and measurements.

LOWER DIVISION

(See Mechanical Engineering Lower Division requirements)

UPPER DIVISION

	Credits
Industrial Engineering Courses	20
IEOR 5000—Introduction to Industrial Engineering Analysis	
IEOR 5010—Introduction to Work Analysis	
IEOR 5020—Engineering Cost Accounting, Analysis, and Control	
IEOR 5030—Quality Control and Reliability	
IEOR 5040—Introduction to Operations Research	
Mechanical Engineering Courses	30
ME 3201—Mechanical Engineering Systems Analysis	
ME 3203—Analysis of Mechanism Systems	
(or) ME 3205—Engineering Systems Design	
ME 3301—Thermodynamics	
ME 3303—Applied Thermodynamics	
(or) ME 5342—Heat Transfer	
ME 3701—Basic Measurements Laboratory I	
ME 3702—Basic Measurements Laboratory II	
ME 3703—Systems Laboratory	
ME 5260—Engineering Materials and Processing	
ME 5254—Design Morphology with Applications	
Liberal Education Electives	18
Coherent Elective Program (see below)	24

Coherent Elective Program—Detailed information on suggested coherent programs of study in the following areas of emphasis, as well as other combinations, are available in the Industrial Engineering Office, 113 Mechanical Engineering Building:

Operations Research
Quality Control and Reliability
Production Engineering
Engineering Statistics
Engineering Management

GRADUATE STUDY IN INDUSTRIAL ENGINEERING AND OPERATIONS RESEARCH

Also, graduate programs in operations research and industrial engineering leading to the M.S. and Ph.D. degrees are available for those students meeting the entrance requirements of the Graduate School.

Landscape Architecture

(School of Architecture and Landscape Architecture)

The problems of relating man and the land are the focus of the professional design field of landscape architecture. Within this focus the landscape architect is concerned with the wise disposition of natural resources as well as with the quality of experience which results for man through land modification for specific human uses. In detail, the landscape architect is concerned with design of the relationships between a specific site with its individual qualities of terrain, soil climate, vegetation, orientation, and views and the program for development with its proposed facilities use areas and circulation needs. Thus, he attempts to secure the most desirable relationships between open spaces and buildings, walks and roads, planting and land forms, in order to best resolve human requirements of utility and beauty in the use of land.

The landscape architect focuses efforts on the design of exterior use areas for a wide range of projects; land used for working, living, and recreation; commercial, institutional, and industrial development; transportation systems and multiple use areas in the regional landscape. Projects vary in scale from the single family environment to regional open space systems. In this regard the professional provides a wide range of design services which include land use feasibility studies, site selection studies, preliminary site layout proposals, detail grading, and construction drawings and planting plans.

Persons interested in entering the field should be committed to solving the problems of effective use of our land and landscape, have a strong interest in nature, and enjoy observing the patterns and qualities of the landscape. A basic interest in drawing and art is a further indication of interest in the profession.

Three undergraduate curricula are offered through the program:

Bachelor of Landscape Architecture—This program is organized to provide the basic professional training for practice of landscape architecture and allow for specialization in one of the expanding areas of professional interest.

This program is offered jointly by the Institute of Technology and the Institute of Agriculture. Students may enroll in either institute. Students registered in the Institute of Agriculture may participate in the resource and community development curriculum and usually select the recreational or the regional design options.

It is strongly recommended that all students show evidence of completing a minimum of 800 hours of practical experience outside of classwork. At least 400 of these hours should be spent in landscape construction or in a landscape nursery and 400 hours in an office of a professional landscape architect. Three months' travel experience may be substituted for half the work experience. Individual study programs as alternatives to the four options may be proposed to the faculty.

Bachelor of Environmental Design (Landscape Architecture)—This program is organized to allow the student to explore a broad range of environmental sources and undertake 2 years of preprofessional studies. Following completion of degree studies, the students may apply for advanced standing for the degree of bachelor of landscape architecture.

A degree is granted to those students showing evidence of completing 400 hours of summer work in landscape architecture.

Individual study programs may be proposed to faculty; these programs may alter this basic curriculum.

Bachelor of Arts (Major in Landscape Architecture)—This program is organized to allow the student to obtain a general liberal education and begin nontechnical professional studies. Following completion of degree studies, the student may apply for advanced standing for the degree of bachelor of landscape architecture.

Details of the program requirements are defined in the *College of Liberal Arts Bulletin.*

ADMISSION PROCEDURES

Upon completion of Lower Division requirements, application shall be made to officially enter the landscape architecture program and initiate design course training for all degrees. This should be done by completing Form LA 110b available from advisers or from the Office of Admissions and Records. *These should be*

submitted not later than July 1 of the year during which the student wishes to begin course work within the school. Admission to beginning design (LA 3081) is normally permitted only in the fall quarter. The prerequisite requirements are met by completing the Lower Division requirements.

Approval of admission will be based on consideration of the following: (a) student's scholastic standing in high school and on previous college work; (b) his maturity and experience; and (c) availability of faculty.

Students who wish to apply for advanced standing within the programs are requested to bring a brochure of their work and a grade transcript to discussions with the advisers in landscape architecture.

BACHELOR OF LANDSCAPE ARCHITECTURE

Lower Division (IT)

	Credits
Core Course Requirements	36
English Composition or Communications	
Three courses in mathematics, statistics, and computer information	
Chem 1004	
Soc 1001	
Econ 1001	

Lower Division (IAg)

	Credits
Care Course Requirements	36
Rhet 1101, 1102, 1022	
Math 1008, 1111	
Chem 1004	
Soc 1001	
Econ 1001	

Following completion of the above the student must apply for admission to the program before June 15 of the year entry to LA 3081 is sought.

Upper Division (IT & IAg)

	Credits
Core Course Requirements	103
LA 1025	
Studio Arts courses (6 credits)	
LA 3101	
LA 3081-3082-3083	
LA 1024	
LA 1022	
AgEn 1400 or CE 3100	
LA 3071-3072-3075	
Soil 1122	
Biology courses (10 credits)	
Hort 1021-1022	
Ecology courses (4 credits)	
Hort 3074	
Geography courses (5 credits)	
Elective Requirements	18
Option Requirements	58

Site Planning and Design Option—Students in this option will focus upon the art and science of developing small-size land areas for intense human usage. Studies are directed toward analyzing microscale environmental determinants as well as aspects of human interaction in detail environments by analyzing the potential subtleties of site organization. Projects will focus upon a range of intensely

developed landscapes including housing, commercial, industrial, education, and urban recreational development.

Recreational Planning and Design Option—The recreational planning option provides an area specialization in the broad spectrum of recreation. The student enrolled in this option will develop special capabilities in park design, golf course design, ski areas, camping facilities, recreational streams and rivers, resort grounds planning, and county or large jurisdictional areas recreation from both the resource and design capability point of view.

Regional Landscape Design Option—Students in this option will focus on large-scale land areas to analyze the development potential, differentiate land uses such as residential, commercial, industrial, recreational, and lands for preservation purposes. Students will prepare analyses and develop other special skills related to the large-scale planning process.

Information concerning the exact course requirements for the various options is available in 110 Architecture Building.

BACHELOR OF ENVIRONMENTAL DESIGN (LANDSCAPE ARCHITECTURE)

Lower Division

	Credits
Core Course Requirements	98
Introductory Composition or Communications (8 credits)	
Three courses in mathematics, statistics, and computer information	
Biology or Botany courses (10 credits)	
LA 1021-1022-1023	
LA 1001-1002-1003	
Art Studio courses (6 credits)	
AgEn 1400 or CE 3100	
Geog 1401	
Geog 1001	
ArtH 1001	
Soil 1122	
Electives (12 credits)	

Following completion of the above the student must apply for admission to the landscape architecture program before June 15 of the year entry to LA 3081 is sought.

Upper Division

	Credits
Core Course Requirements	92
LA 3081-3082-3083	
Art Studio courses (6 credits)	
Ecology courses (4 credits)	
Hort 1021-1022	
LA 3091-3092-3093	
LA 3071-3072-3075	
LA 5115	
Electives (24 credits)	
Total Credits	190

Mathematics

The School of Mathematics offers a 4-year curriculum leading to the degree of bachelor of mathematics, B.Math.

In addition to the prescribed courses listed below, for graduation a student must meet the minimum Liberal Education requirement for the Institute of Technology and have sufficient approved electives to total 186 credits.

The course of study is very flexible and can easily be adapted to the needs and interests of all students who wish to concentrate in mathematics as an undergraduate. Sample curricula are available in the departmental offices (127 Vincent Hall) exemplifying ways in which the graduation requirements can be met by programs emphasizing diverse goals and fields of interest such as: graduate school preparation, applied mathematics, engineering science, computer science, actuarial science, etc. Students are encouraged to develop individualized programs in consultation with their adviser and the director of undergraduate studies of the School of Mathematics.

A combined 5-year curriculum is offered in cooperation with the College of Education leading to two degrees, bachelor of mathematics and master of education.

LOWER DIVISION

Students majoring in mathematics are expected to acquire during their first 2 years a knowledge of the following subjects (in each case the requirement may be met by the course work alternatives listed):

1. Calculus of functions of a single variable
   Math 1211-1221-1231
   Math 1311-1321-1331
   (or) Math 1611-1621
2. Elementary Computer Programming
   CICS 1100
   (Students who elect to take 1311-1321-1331 to satisfy requirement 1, automatically satisfy requirement 2 and need not take CICS 1100)
3. Multi-Variable Calculus, Linear Algebra and Differential Equations
   Math 3511-3521-3531
   Math 3211-3221
   Math 3211, 3142 and either 3066 or 5521
   (or) Math 3611-3621 and either 3066 or 5521
   (Students electing the latter options may also use Math 5521 to satisfy Upper Division requirements)
4. General Physics
   Phys 1271, 1281, 1291
   (Students must have 1 quarter of calculus before starting this sequence; the associated laboratory course, Phys 1275, 1285, 1295, is recommended but not required)

Mathematics majors who take Math 1211-1221-1231 or 1311-1321-1331 are urged to take Math 3511-3521-3531. Those who take Math 1611-1621 should take 3611-3621. Students who do not take Math 3531 are strongly urged to take 3675 before attempting 5000-level mathematics courses.

In addition to the above, students majoring in mathematics will normally take up to 32 credits of electives during their first 2 years. These electives should include Comp 1001, 1002 and at least 18 credits toward the Liberal Education requirement.

UPPER DIVISION

1. All mathematics majors are required to take 48 credits of mathematics at the 5000 level, and the following minimum requirements must be satisfied:

Analysis Requirement—Completion of one of the following sequences:

Math 5601-5602-5603—Advanced Calculus
Math 5612-5613-5614—Introduction to Analysis

Algebra Requirement—Completion of one of the following sequences:

Math 5242-5243—Linear Algebra with Applications
Math 5282-5283-5284—Fundamental Structure of Algebra

Depth Requirement—Completion of one of the following sequences:

Math 5157-5158-5159—Mathematics of Symbol Manipulation Systems
Math 5162-5163-5164—Mathematical Logic
Math 5209, 5244—Theory of Numbers; Group Theory
Math 5341-5342-5343—Introduction to Topology
Math 5366-5367-5368—Geometry
Math 5375-5376-5377—Differential Geometry
Math 5457-5458-5459—Methods of Applied Mathematics
Math 5521-5522-5523—Introduction to Ordinary Differential Equations
Math 5541-5542-5543—Special Functions in Mathematical Analysis
Math 5571-5572-5573—Elementary Partial Differential Equations
Math 5681-5682-5683—Introduction to Probability
Math 5701-5702-5703—Combinatorics

Other sequences may satisfy the depth requirement by petition. The student should check with his adviser.

2. In addition to the above requirements, a mathematics major must have a 12-credit technical elective from among the following:

a. Any Upper Division sequence in the Institute of Technology (or)
b. Any Upper Division sequence requiring differential and integral calculus as a prerequisite.

COMBINED MATHEMATICS AND EDUCATION CURRICULUM

The combined 5-year curriculum between mathematics and the College of Education leads to the two degrees, bachelor of mathematics (B.Math.) and master of education (M.Ed.).

A student may apply for this curriculum during the third quarter of his junior year. He should have at least a C+ average (2.50) in all courses and a B— average (2.75) in mathematics. In addition, he must complete the speech, health, and psychological examinations and interviews required by the College of Education and secure the approval of his major adviser in mathematics in the Institute of Technology and the Admission Committee of the College of Education.

The student carries courses in both colleges concurrently during the fourth and fifth years and is awarded both degrees when he meets the following requirements. He must complete the prescribed courses in both colleges and a total of 231 credits. These must include 45 credits at the 5000 or 8000 level in mathematics and education (minimum of 32 in mathematics) with a B (3.00) average.

Students are advised to obtain a statement of current requirements for the master of education degree at 206 Burton Hall, the Student Personnel Office. In the third quarter of the third year (junior year) the student should apply for the

joint program at the Transfer Window, Office of Admissions and Records, Morrill Hall. At the same time he should apply for student teaching at 227 Burton Hall. During the third quarter of the fourth year the student should apply for transfer to the College of Education at the Transfer Window, Morrill Hall.

Students in this program are required to satisfy a minor as described in the *College of Education Bulletin*. Normally the minor is in physics, in which the student is required to take the laboratory sequence Phys 1275/1285/1295. (Students minoring in physics must take SeEd 3352, which is offered only in the spring quarter.) Consult *College of Education Bulletin* for further details. The minor should be completed before the end of the third year of studies.

The required courses for this curriculum are the same as those appearing under the B.Math. degree with the following exceptions:

1. The requirement of 48 credits of Upper Division mathematics courses may be satisfied by substituting Math 3161 or 3675 or 3581 or 3582 or 3583 for any 5000-level course.
2. Math 3161 is a required course for students in this program and should be taken before the end of the third year of studies.
3. Psy 1001 is required and should be taken before the end of the second year.
4. SeEd 3150, 3155, 3365, 3366, 3367, 3661 are required and should be taken before the end of the fourth year.
5. In addition SeEd 3352, HEd 3090 and MthE 8500, 8680 (9 credits), 8980 (3 credits) are required. (Since MthE 8680, 8980 require placement in a secondary school and the writing of an internship paper, students must consult the instructor listed for these courses at the time of registration.)

A student should consult with the College of Education early in his program to make sure that he satisfies the requirements for admission to the College of Education.

A sample program of study is available in the School of Mathematics office, 127 Vincent Hall.

CLA students interested in obtaining simultaneously the B.A. degree and the B.S. in education should see the *College of Liberal Arts Bulletin* for details.

Mechanical Engineering

Mechanical engineering is involved in most technological activities of society and dominates many. These include, among others, the automotive, transportation, and materials handling fields, environmental and pollution control systems, refrigeration and cryogenics, design of nuclear and conventional power systems, automation and control systems, and the production of machinery and consumer products. The mechanical engineer may be engaged in design, development, research, testing, manufacturing, administration, sales engineering, or education.

The department program provides the scope and emphasis necessary for eventual engineering employment in these fields. The undergraduate receives a strong background in the basic sciences of mathematics, physics, and chemistry balanced with courses in engineering science and applied engineering. Through a broad pattern of electives, each student has an opportunity to develop a program of study that reflects his particular area of interest.

Degree Requirements—The 4-year curriculum requires 184 quarter credits which leads to the degree of bachelor of mechanical engineering, B.M.E.

ELECTIVE PROGRAMS

The Department of Mechanical Engineering, together with the Department of Aeronautics and Engineering Mechanics, form the School of Mechanical and Aerospace Engineering. Interdisciplinary programs involving the two departments are currently under development and until these are more formalized, the student is encouraged to work with his adviser in formulating any cross-disciplinary programs which may meet his particular objectives.

For mechanical engineering, the total elective program consists of a minimum of 28 liberal education electives and a coherent program of approximately 30 credits. Thus the student has the responsibility to select about 58 credits of course work. It is anticipated that the student will work closely with his adviser to plan an adjunct elective program. Details of suggested programs are available in 125 Mechanical Engineering Building and some are enumerated below:

1. Power and Propulsion
2. Design and Controls
3. Thermodynamics and Heat Transfer
4. Materials Engineering
5. Environmental Engineering
6. Industrial Engineering/Operations Research
7. Bioengineering
8. Electro-Mechanical Engineering
9. Transportation Emphasis

ENGINEERING INTERN PROGRAM

A mechanical engineering intern program is available during the last 2 years of study. The program provides for alternate quarters of industry assignments. Formal application is necessary by January 1 of the sophomore year. More specific information is available in 125 Mechanical Engineering Building.

INDUSTRIAL ENGINEERING/OPERATIONS RESEARCH PROGRAM

This program differs somewhat from the regular mechanical engineering program. Further descriptive information is available under course descriptions.

GRADUATE STUDY IN MECHANICAL ENGINEERING

Information regarding a professionally oriented Master's degree in mechanical engineering and industrial engineering within the Institute of Technology is available in the Mechanical Engineering Department office, 125 Mechanical Engineering Building. In addition, both the Ph.D. and M.S. degrees with a major in mechanical or industrial engineering are available for those students meeting the entrance requirements of the Graduate School.

COURSE REQUIREMENTS

The Lower Division program provides course work in basic and engineering science preparatory to the Upper Division. The Upper Division includes additional engineering science and applied engineering subjects, including measurements and design. Additional information, alternate courses, coherent elective information, and specialized preparation is provided in supplemental department bulletins available in 125 Mechanical Engineering Building or through your adviser.

LOWER DIVISION

	Credits
English Composition or Communications	8
Math 1211, 1221, 1231, 3221; ME 3900**—Analysis I, II, III, Linear Algebra and Differential Equations; Engineering Statistics	24
Phys 1271, 1281, 1291—General Physics	12
Phys 1275, 1285, 1295—Physics Laboratory	3
Chem 1014** (additional chemistry, biology, ecology or geology)	8
Introduction to Engineering**	7
EG 1025—Graphics	
CICS 1100—Introduction: FORTRAN Programming	
ME 1001—Introduction to Mechanical Engineering	
Engineering Science	16
AEM 3036—Dynamics	
AEM 3016—Deformable Body Mechanics	
EE 3000**—Circuits	
CE 3400—Fluid Mechanics	
Electives	4
Liberal Education Electives	10
Total Credits	92

UPPER DIVISION

	Credits
Basic Engineering Program	40
ME 3301, 3303, 5342—Thermal Engineering	
ME 3201, 3203, 3205—Mechanical Engineering Systems and Design	
IEOR 5000—Industrial Engineering	
EE 3001—Electronics (EE 1501 for those taking 1500 in Lower Division)	
ME 5260—Materials Engineering and Processing	
ME 5254—Design Morphology with Applications	
Laboratory Program	8
ME 3701-3702—Basic Measurements Laboratory I, II	
ME 3703—Advanced Mechanical Engineering Laboratory (4 credits)	
Liberal Education Requirement (sufficient to meet liberal education requirements)	18
Coherent Elective Program††	26
Total Credits	92

Metallurgy/Materials Science

(Department of Chemical Engineering and Materials Science)

The metallurgist or materials engineer selects and develops metals and alloys, ceramics, and plastics to meet a large number of diverse engineering needs. These engineers sometimes develop materials for extremely small devices such as micro-

** For a complete Lower Division description, alternate courses, and suggested scheduling, obtain curriculum handout in 125 Mechanical Engineering Building.

†† See information on coherent elective programs under degrees offered and obtain information bulletins in 125 Mechanical Engineering Building.

electronic components or they may make large parts such as rotors weighing many tons for turbines in electric generating plants. Large complex machines such as earth moving equipment are made of many different materials tailored for particular tasks. The materials must be dependable under extremes of load and environment. The materials must be produced in a manner compatible with the ecological balance. Frequently the engineering application requires a new material which possesses a particular combination of properties which are not found in conventional materials. To develop these materials the metallurgist or materials engineer must understand the detailed nature of materials and how they behave.

Materials engineers are responsible for producing materials in industries specializing in metal- and polymer-producing industries. They are also responsible for advising design engineers in many diverse fields and industries in the proper selection of materials. As new products are developed, the materials engineers are responsible for the performance testing and analysis of the component parts of the product.

Materials engineers are indispensible to virtually every product-related industry—to the nuclear industry for developing long-term reliable containment materials for fission and fusion processes; to the chemical industry for selecting and developing materials to hold exotic combinations of temperature and environment in chemical reactors; to the consumer advocates for providing the materials specialists who can both analyze material failures and recommend solutions for increased product reliability; to the aircraft industry for innovating fatigue, fracture, corrosion, and heat-resistant materials which are used from the landing gear to the engine cowling; to the communication industry for providing unique semiconductor devices which have allowed and will continue to represent the advances made in electronic circuitry; to other high-technology areas such as oceanspace and aerospace where new breeds of metal alloys allow the breakthrough of existing time-environment barriers; to the oil and gas industry for providing the basic tools with which the products are extracted and transported; to the automotive industry, for developing high-strength, heat-resistant materials for low emission gas turbine or steam engines; to the medical and dental professions for creating and evaluating potential prosthetic materials; to the power industry for developing efficient superconducting materials capable of transmitting large electrical quantities.

A curriculum leading to a bachelor of metallurgical engineering, B.Met.E., is based on a background in mathematics through simple differential equations, physics through modern physics, and 6 quarters of additional technical courses which include chemistry, ecology, and deformable body mechanics. This 2-year course of technical content is supplemented by 16-20 credits of English and liberal arts.

Built upon this background are 2 years of professional specialization consisting of fundamental courses in materials science, thermodynamics, physical metallurgy, mechanical metallurgy, polymer engineering and corrosion. Laboratory work related to the study of the structure and properties of materials is an integral part of this professional preparation.

On the Twin Cities Campus, the first 2 years of the curriculum are generally the same as other Lower Division engineering curricula. The flexibility is such that either normal engineering or chemical engineering tracks may satisfy departmental criteria as typified by the following Lower Division programs.

NORMAL ENGINEERING PROGRAM SATISFYING MATERIALS SCIENCE REQUIREMENTS

LOWER DIVISION

First Year

	Credits—f,w,s		
Math 1211, 1221, 1231—Analysis I, II, III	5	5	5
Chem 1031 (or equivalent)—General Principles of Chemistry	5	..	..
Natural Science or Approved Technical Electives	..	4-5	5-9
Comp 1001, 1002—Introductory Composition	4	4	..
Liberal Education Electives	0-4	0-4	4-8

Second Year

ME 3900 (or) Math 3211—Introduction to Engineering Statistics; Analysis IV	4-5	..	..
Math 3221—Linear Algebra and Differential Equations	..	5	..
Phys 1271, 1281, 1291—General Physics	4	4	4
Phys 1275, 1285, 1295—General Physics Laboratory	1	1	1
EBB 3101 (or) GCB 3201—Ecology; Biology	..	(4)	(4)
AEM 3016 (and/or) AEM 3036 (and/or) CE 3400—Engineering Science (Deformable Body Mechanics; Dynamics; Fluid Mechanics)	..	0-8	0-8
Technical Electives	4-5	..	0-5
Electives	0-4	0-4	0-4

NORMAL PRE-CHEMICAL ENGINEERING PROGRAM SATISFYING MATERIALS SCIENCE REQUIREMENTS

LOWER DIVISION

First Year

	Credits—f,w,s		
Chem 1031, 1032, 1034—General Principles I, II, Synthesis I	5	5	5
Math 1311, 1321, 1331—Computer Calculus I, II, III (or) Math 1211, 1221, 1231—Analysis I, II, III	5	5	5
Comp 1001, 1002—Introductory Composition	4	4	..
Electives (may be rearranged with Engl 1001, 1002)	..	0-4	4-8

Second Year

Chem 3034, 3201, 5126—Synthesis II, Rates and Mechanisms, Modern Analytical Chemistry	5	5	5
Phys 1271, 1281, 1291—Mechanics, Heat and Electricity, Magnetism and Optics	4	4	4
Phys 1275, 1285, 1295—General Physics Laboratory	1	1	1
Math 3211, 3221—Analysis IV, Linear Algebra and Differential Equations	5	5	..
AEM 3016—Deformable Body Mechanics (or) Math 3231—Vector Analysis	..	..	4
EBB 3101—Ecology for Students of Physical Science	..	4	..
GCB 3201—Molecular Biology (or approved biology alternative)	..	..	3-4

NORMAL PRE-MATERIALS SCIENCE PROGRAM ON TWIN CITIES CAMPUS

LOWER DIVISION

First Year

	Credits—f,w,s		
Math 1211, 1221, 1231—Analysis I, II, III (or) Math 1311, 1321, 1331—Computer Calculus I, II, III	5	5	5

Chem 1031—General Principles of Chemistry	5	..	..
I of T 1003, MatS 1002—Engineering; Introduction to Materials	1	2	..
Chemistry or Approved Technical Electives	..	4-5	4-9
Comp 1001, 1002—Introductory Composition	4	4	..
Electives (may be rearranged with Engl 1001, 1002)	..	0-4	4-8
Second Year			
Phys 1271, 1281, 1291—Mechanics, Heat and Electricity, Magnetism and Optics	4	4	4
Phys 1275, 1285, 1295—General Physics Laboratory	1	1	1
Math 3211, 3221—Analysis IV, Linear Algebra and Differential Equations	5	5	..
EBB 3101—Ecology for Students of Physical Science	..	4	..
AEM 3016—Deformable Body Mechanics	..	..	4
Technical Electives	4-5	..	0-5
Electives	0-4	0-4	4-8

REQUIREMENTS FOR B.MET.E. DEGREE

1. Completion of the Lower Division requirements, as exemplified by the numbered courses in the normal materials science program shown above. Before the completion of requirements can be certified, the student must have finished 90 quarter credits which represents the normal progress toward a B.Met.E. degree.

Transfer Students—Most students intending to transfer from another campus or school with a general engineering Lower Division standing have satisfied most course requirements or have equivalents. For more specific information they are encouraged to write or visit the Department of Chemical Engineering and Materials Science, University of Minnesota, Minneapolis 55455. Students can obtain certification of completion of the Lower Division requirements at the time of transfer.

2. Completion of the Institute of Technology Minimum Liberal Education Requirement, which is described on pages 60 and 61. That requirement totals 36 credits, of which 8 are Freshman English or substitutes, and 7 or 8 are EBB 3101 and GCB 3201 or substitutes. Of the remainder, at least 12 credits must be in Category 3, "Man and Society," and at least 8 must be in Category 4, "Artistic Expression." Thus, of all the free elective credits in the Lower Division and Upper Division programs in materials science shown here, 20 or 21 should be devoted to completing the Liberal Education requirement.

3. Completion of a coherent Upper Division program of scientific and technical courses. A student in conjunction with his adviser designs his program in two stages: a 1-year plan for the third year must be filed by the beginning of that year; and ordinarily by the beginning of the fourth year a complete 4-year program must be submitted for certification by the department. The student then receives his degree upon completing all courses in his program with a GPA of 2.00 or better. His program must total at least 180 quarter credits, the minimum required for the B.Met.E. Normal 4-year programs contain more than 180 credits.

The Upper Division program must be a coherent program of scientific and technical courses approved by the student's adviser. This program may be oriented toward metallurgy or materials science. It may emphasize engineering courses for students who wish to enter industry with a baccalaureate degree or it may emphasize scientific topics which serve as a background for graduate work. Coherent

programs which illustrate these possibilities are available from the advisers or the departmental office, 151 Chemical Engineering Building. Advisers and the department's director of undergraduate studies can be contacted through the same office. The following is a basic Upper Division Program.

BASIC PROGRAM IN MATERIALS SCIENCE

UPPER DIVISION

Third Year

	Credits	f,w,s	
MatS 5011, 5012, 5013—Introduction to Materials Science	4	4	4
Chem 5505—Statistical Thermodynamics	4	..	..
ChEn 5001—Mathematical Methods	2	..	..
MatS 5101, 5102—Thermodynamics and Kinetics	..	4	4
MatS 3521, 3501—X-Ray and Quantitative Metallography	3	3	..
Technical Elective	..	..	4
Electives	0-4	4	4

Fourth Year

MatS 5401, 5402, 5403—Principles of Physical Metallurgy	4	4	4
MatS 5301—Advanced Mechanical Metallurgy	4	..	..
MatS 5303—Analysis of Metallurgical Problems	..	..	4
MatS 5610—Introduction to Polymers	..	4	..
MatS 5450 (or) Chem 5502 (or) Phys 3501—Corrosion of Metals; Quantum Mechanics; Modern Physics	..	0-4	0-4
AEM 5580 (or) ME 5207—Mechanics of Elastic Solids I; Experimental Stress	4	..	..
Technical Elective	..	0-4	0-4
Electives	4	3-4	3-4

Mineral Engineering

(Department of Civil and Mineral Engineering)

Mining and petroleum engineering production processes are concerned with the development, production, and management of mines and oil fields, involving design of production systems and plants and their economic analyses. The mining engineer must know the principles of ore deposits, their exploitation, and beneficiation, while the petroleum engineer must be familiar with oil geology and the nature and behavior of reservoir and aquifier fluids.

Mineral and metal extractive processes are based on the principles of physics, chemistry, and engineering as applied to the beneficiation of ores and of other mineral aggregates; with the extraction of metals from their ores and beneficiated products; and frequently with the purification of the metals won by these processes. Beneficiation includes such areas as comminution, and gravity, magnetic and flotation concentration; hydrometallurgy embraces the leaching of ores; pyrometallurgy deals with the high-temperature operations of roasting, agglomeration, smelting, and refining.

The education of the mineral resources engineer is based on scientific and engineering principles to prepare him for a varied demands of his profession and yet not confine him to a narrow specialty. The preparation is broad, not only in the basic and allied engineering sciences but also in geology and economics. The two broad areas of study overlap somewhat as the production engineer and the extractive engineer must be knowledgeable of each other's specialties. Common to both

study areas is mineral economics, which illuminates the probabilities of success or failure of a mineral venture. These subjects deal with supply and demand of mineral commodities, examination and evaluation of mineral properties and projects, and problems of financing, depletion, and conservation, among other things. Environmental aspects of the mineral industry are treated in all of the courses presented.

Mineral resources engineering blends into a unified and balanced program the disciplines of (a) mineral and petroleum production processes, and (b) mineral and metal extractive processes. Through the proper selection of technical electives a student may broaden and deepen curriculum preparation in the area of his principal interests. The field is closely allied with geo-engineering.

The Mineral Resources Research Center is an integral part of the Department of Civil and Mineral Engineering. Staff members teach many of the undergraduate courses in mineral processing and extractive metallurgy. The center has extensive pilot plant and laboratory facilities which provide a unique opportunity for the training of students in the mineral engineering field.

A 4-year curriculum is offered that leads to the degree of bachelor of mineral engineering (B.Min.E.). A total of 184 credits (or equivalent demonstrated competence), including field trips, is required for graduation.

The following is a recommended program which can be modified, in consultation with a faculty adviser, to better meet individual student interests.

LOWER DIVISION

(90 Credits) Credits

English Composition or Communications	8
Math 1211, 1221, 1231, 3211, 3221—Analysis I, II, III, IV, Linear Algebra and Differential Equations	25
Phys 1271, 1275, 1281, 1285, 1291, 1295—General Physics (with Laboratory)	15
Chem 1004, 1005 and 1006—General Principles of Chemistry, Principles of Solution Chemistry (recommended)	10-14
I of T 1010 (or) EBB 3101—Ecology	4
AEM 1015—Statics	4
CE 3010 (or) ME 3900—Engineering Statistics	4
CICS 3101 (or) CICS 1100—FORTRAN Introduction to Computer Programming	4
CE 3400 (or) MinE 5825—Fluid Mechanics; Principles of Metals Extraction II	4
Liberal Education Elective	8-12

UPPER DIVISION—MINERAL PROCESSING AND EXTRACTIVE METALLURGY OPTION

(94 Credits) Credits

Junior Year

MinE 5611, 5612, 5613—Mineral Engineering I, II, III	12
MinE 5800, 5810, 5820—Mineral, Metal Extraction I, II, III	12
Geo 1111, 3401—Physical Geology, Introductory Mineralogy	10
MinE 5830—Microscopic Techniques for Mineral Engineers	3
GeoE 5437—Computer Applications in Geo- and Mineral Engineering	4
MinE 5825—Metallurgical Heat Transfer and Fluid Flow	4
Liberal Education Electives	4

Senior Year

Credits

Chem 5520, 5521—Elementary Physical Chemistry	8
EE 3460—Electrical Machinery and Power Distribution	5
MinE 5700—Systems Analysis for Mineral Engineers	4
MatS 3400—Mechanical Properties of Materials	4

MinE 5710—Environmental Engineering for Mineral Engineers 4
MinE 5910—Metallurgical Unit Processes 4
MinE 5652—Mineral Engineering Design II 4
MinE 5818—Hydrometallurgy 4
Liberal Education Electives 12-16

UPPER DIVISION—MINERAL PRODUCTION OPTION

Junior Year

	Credits
MinE 5611, 5612, 5613—Mineral Engineering I, II, III	12
MinE 5800, 5810, 5820—Mineral, Metal Extraction I, II, III	12
Geo 1111, 3401—Physical Geology, Introductory Mineralogy	10
Geo 3103—Structural Geology	5
GeoE 5216—Rock Mechanics I	4
CE 3100—Surveying	4
GeoE 3012—Geo-Engineering Survey (optional)	2
Liberal Education Electives	4

Senior Year

	Credits
MinE 5630—Surface Mining	4
EE 3460—Electric Machinery and Power Distribution	5
MinE 5700—Systems Analysis for Mineral Engineers (or) GeoE 5351, 5352 (without lab)—Ore Deposits	3-4
MinE 5650, 5652—Mineral Engineering Design I, II	8
GeoE 5437—Computer Applications in Geo- and Mineral Engineering	4
MinE 5710—Environmental Engineering for Mineral Engineers	4
MinE 5830—Microscopic Techniques for Mineral Engineers (or) MinE 5825—Metallurgical Heat Transfer and Fluid Flow (or) Geo 5352—Ore Deposits	3-4
Liberal Education Electives	12-16

Physics

Since physics is concerned with the description of the fundamental properties of the physical universe, the physics curriculum may appeal to students with many diverse educational objectives. Some seek employment after receiving the Bachelor's degree, often in an industrial or government laboratory. Others will pursue further study, either in physics or in such diverse areas as biology, medicine, law, or business. Students interested in careers as high school teachers may wish to consider the 5-year program leading to the B.Phys. and an M.Ed. in science, or the 4-year program in the College of Education leading to a B.S. with a major in physics. Both programs lead to certification. Information on these programs is available in the undergraduate office, 148 Tate Laboratory of Physics.

It has been the department's experience that unless most of a student's grades in his freshman mathematics and physics courses are A or B, he will have difficulty pursuing a physics major.

Because of the diverse interests of students pursuing this degree, the required courses have been designed to give the student a broad foundation in experimental and theoretical physics. The required courses represent a minimum program, and students preparing for particular careers will want to take more physics courses than are required. Many elective courses are available, and the student should consult his faculty adviser or the undergraduate office to plan his program. Sample programs for various interests are available in the undergraduate office.

A course of study totaling 180 credits is required for the degree. This assumes that the student has satisfied the IT requirement in English composition and that he has taken 3 years of foreign language in high school.

If a student must take English composition courses at the University of Minnesota, the number of credits he takes is added to the graduation requirement. This can raise the number of credits required for graduation by as much as 8 credits.

If the student has not had 3 years of foreign language in high school, he must complete the third quarter of a foreign language at the college level. For this purpose German, Russian, or French is recommended. These language courses are usually 5 credits per quarter. Of the 5 credits for each college-level course, 3 are added to the graduation requirement, and 2 may be applied toward the "remaining courses" in the Liberal Education requirement described below. For a student who must take three language courses (15 credits) at the college level, this means that the graduation requirement is raised by 9 credits, and 6 credits are applied toward the Liberal Education requirement.

To summarize the effect of English composition and foreign language on the number of credits required for graduation:

	Credits
English composition and language satisfied in high school	180
Must take 8 credits English composition; language satisfied	188
Must take 15 credits of language; English satisfied	189
Must take both English composition and language	197

GRADUATION REQUIREMENTS

(Based on 180 Credits) Credits

Liberal Education 36

Of these 36 credits, at least three courses (12-15 credits) must be in Category 3 (Man and Society), and at least two courses (8-10 credits) must be in Category 4 (Artistic Expression). The remaining courses may be in any category except 1d (Mathematics) or 2a (the Physical Universe). At least two of the courses must be Upper Division (3000 level) or Upper Division/Graduate (5000 level).

Mathematics

Math 1211, 1221, 1231 (or) Math 1311, 1321, 1331, (or) Math 1611, 1621 ... 10-15
Math 3211, 3221, 3231 14
Two additional courses 8-10

Required Physics Courses

1. Phys 1271-1281-1291—General Physics 12
   Phys 1275-1285-1295—General Physics Lab 3
2. Phys 3011—Oscillations 4
   Phys 3012—Waves and Optics 4
3. Phys 3511-3512-3513—Modern Physics 12
4. Phys 3015—Laboratory in Oscillations and Waves 1
   Phys 3515—Physics Laboratory 1
5. Either of the following sequences: 16-20
   a. Phys 5021-5022—Introduction to Analytic Mechanics (*and*) Phys 5023-5024—Introduction to Electric and Magnetic Fields
   b. Phys 5011-5012-5013—Mechanics, Electricity, and Magnetism (*and*) Phys 5101-5102—Introduction to Quantum Mechanics
6. One course in advanced laboratory (5120 or 5804) and one additional course in either advanced laboratory or electronics 8-9
7. Physics electives to total 70 credits 4-9

Electives to total 180 credits 35-42
180

English and/or Foreign Language as required 0-17

Total Credits 180-197

Electives—There are 4-9 credits of required physics electives and 35-42 credits of completely unspecified electives. Because the specified physics courses represent a minimum requirement, most students will want to take some of these electives in physics or allied areas.

Some of the recommended electives for students interested in graduate school or a career in industry are shown below. More extensive lists are available in the undergraduate office, 148 Tate Laboratory of Physics.

Electives Suggested for Students Interested in Graduate School:

Option 5a above, with Quantum Mechanics (Phys 5101-5102) as an elective
Introduction to Electric and Magnetic Fields (Phys 5025)
Thermodynamics, Statistical Mechanics (Phys 5201-5202)
Advanced Laboratory (additional)
Electronics (Phys 5851, 5852, 5853)
One quarter specialty courses (e.g., nuclear, solid state, elementary particle physics, contemporary optics, etc.)
Astronomy (Ast 3051, 5161, 5162)
Mathematics
Chemistry
Computer Programming
Classical Physics (Phys 5051-5052-5053)
Quantum Mechanics (Phys 5151-5152-5153)

Electives Suggested for Students Interested in Industrial Employment:

Electronics (Phys 5851, 5852, 5853)
Chemistry
Advanced Laboratory (additional)
Computer Science
Specialty courses
Thermodynamics (either as physics or chemistry)
Materials Science
Electrical Engineering
Aerospace and Engineering Mechanics (fluid, mechanics, elasticity, acoustics)
Geophysics

III. ACADEMIC REQUIREMENTS

Liberal Education Requirement

Institute of Technology students, whatever their area of specialization, hold in common with all University students the search for a liberal education—one which enhances their powers of judgment and choice. A liberal education implies awareness of the intellectual instruments for acquiring and communicating knowledge, primarily the instruments of language and structure, understanding of the ways in which engineers and scientists contribute to man's knowledge of himself and his environment, historical and philosophical perspective on the nature of the individual and society, and appreciation of the role of literature and the arts in the interpretation of life and nature.

The Institute of Technology faculty accepts the divisions of knowledge, outlined below, as developed by the All-University Council on Liberal Education. The Institute of Technology Minimum Liberal Education Requirement, together with required courses in English, mathematics, and the physical sciences, exceeds the basic all-University requirements of the Council on Liberal Education. Courses to meet the Minimum Liberal Education Requirement are to be selected from the course catalog available in department offices and in 105 Main Engineering Building. Students are urged to select courses in coherent sequences from the required categories.

Minimum Liberal Education Requirement—In addition to required courses in mathematics and the physical sciences (which meet or exceed the all-University requirements for categories), a minimum of 36 credits of liberal education courses are required, subject to the following distribution requirement:

1. Two courses (8-10 credits) of English composition with a maximum of 4 credits earned by means of a technical writing course or special reports. If a student is exempted from Freshman English, the 8-10 credits may be made up in item 3 below.
2. Three courses (12-15 credits) in Category 3, Man and Society.

Afro 1015, 1036-1037, 1441, 1442, 3001-3002-3003, 3061, 3075, 3076, 3081-3082, 3091, 3092, 3098, 3455, 3551, 5001-5002, 5101, 5102, 5103, 5401
AgEc 1010, 1020
AmIn 1101, 1102, 1041, 3061, 5112, 5121, 5131, 5570, 5990
AmSt—All courses
Anth—All courses except 5421 (now 5161)
Arab 3511-3512-3513, 3531, 3551-3552-3553
Arch 1001-1002-1003
CJS—All courses
Clas 1001, 1002, 1003, 1004, 1005, 1006, 1011, 1022, 1033, 1042, 1044, 1055, 1066, 1142, 3071, 3072, 3073, 5004, 5071, 5072, 5073
CPsy—All courses
Econ—All courses
EPsy 5121, 5122
FSoS—All courses
Fren 3501-3502-3503
Geog—All courses except 1425
Ger 5331
Grk 5794
Heb 3131-3132, 3501, 3502
Hist—All courses
Hum—All courses
Indc 1501-1502-1503, 1504-1505-1506, 3504-3505-3506, 3507, 3533, 5511-5512, 5520, 5531-5532-5533

Ital 3501-3502-3503
Jour 1003, 1701, 3021, 3776, 5501, 5514, 5601, 5603, 5611, 5615, 5721, 5801, 5825, 5826
Lat 5794
LatAmSt 5101
Lib 5001, 5221
MidESt 3125, 3501, 3502, 3503, 3555
MilSci 21, 22, 23 (if taken 1968-69 or 1969-70)
NSci 5171-5172-5173
Ortl 3501, 3502
Pers 3501, 3502
Phil 1002, 1003, 1004, 3001, 3002, 3003, 3004, 3202, 3302, 3415, 5003, 5005, 5008, 5021, 5033, 5034, 5035, 5036, 5041, 5042, 5043, 5044, 5054, 5301, 5302, 5311, 5401, 5414, 5521, 5611, 5612, 5621, 5781, 5801
Phys 5901, 5902, 5903
Pol—All courses except 3085
Pys—All courses
RelS 1031-1032-1033, 3970, 3999
Russ 3501, 3502, 3503
Scan 1504, 3501
SSci—All courses
SW—All courses
Soc—All courses
Span 3001-3002-3003
Spch 1103, 3401, 5211, 5222, 5231, 5232, 5233, 5401, 5402, 5403, 5421, 5431, 5432, 5441, 5451, 5602

3. Two courses (8-10 credits) in Category 4, Artistic Expression.
Afro 1301
AmIn 5211
AmSt—All courses
Arab 3201-3202-3203, 3351, 5211-5212
Arch 1021, 1022, 1023, 5051, 5052, 5053, 5054, 5055, 5056
ArtH—All courses
ArtS—All courses
Clas 1009, 3009, 3081, 3082, 3083, 3091, 3092, 3093, 5081, 5082, 5083, 5091-5092-5093, 5107-5108-5109, 5115
Chin 5201, 5202, 5203
Engl—All courses except 3601, 5633, 5646, 5666, 5667, 5674
Foreign Languages: Any upper division foreign literature course may be used in this area.
Fren 3601-3602-3603
Ger 3104, 3105, 3201, 3202, 3203, 3301, 3302, 3303, 3311, 3312, 3313, 3321, 3322, 3323, 3331, 3332, 3341, 3342, 3401, 3402, 3403, 3601, 3602, 3603
Grk 1104-1105, 3106-3107, 3368, 3375, 3376, 3377, 3378, 3379, 3461, 3464, 3471, 3474, 5264, 5265, 5266, 5371, 5372, 5373, 5374, 5375, 5376, 5377, 5378, 5379, 5381
HE 1501, 1521, 1541
Heb 3201-3202-3303, 3121-3122-3123, 3301-3302-3303
Hum—All courses
Indc 3201-3202-3203, 5301, 5302, 5401, 5802
Ital 3601-3602-3603
Jap 5201, 5202, 5203
Jour 3221, 5606, 5171
LA 1021, 3062-3063
Lat 1104-1105, 3106, 3461, 3462, 3463, 3464, 3465, 3466, 3467, 3468, 3469, 3471, 3472, 3473, 3474, 3475, 3476, 3477, 3478, 3479, 5235, 5364-5365-5366, 5371, 5372, 5373, 5374, 5375, 5376, 5377, 5378, 5379, 5715
MdGk 1104-1105-1106
MidE 3103
Mus—All courses
MuEd 3557
Pers 5990
Phil 5501, 5911
Russ 3601-3602-3603, 5403, 5409

Scan 5503, 5512, 5601, 5631, 5632, 5633, 5670
Spch 3201, 3202, 3203, 3204, 5201, old 81-82, 5204
Span 3611, 5416
Th—All courses

4. Additional credits may be in any category except courses in astronomy, chemistry, CICS, geology, mathematics, and physics. These additional credits may include courses in the biological sciences and ecology unless specifically excluded by the student's department. Furthermore, students are strongly urged to take courses which study the impact of science and technology on society and the environment.

The above lists of courses are EXAMPLES ONLY and do not include all of the courses which may fulfill the requirements.

Courses required in a specific curriculum, which otherwise meet the distribution requirements above, can apply toward the IT Liberal Education Distribution Requirements.

Normally, students are expected to meet the specific category requirements; *however*, in cases where students in planning what they believe to be a coherent program find themselves over in one category and short in another, this imbalance will in all probability be approved if the student petitions and asks for permission to take a particular program or to be exempted from the total credit requirement of a certain category.

Students are encouraged to take higher-level courses and deepen their knowledge of some area in which they are interested. The prerequisites of upper division courses are often quite modest. In addition, students who feel that their education is better served by a certain amount of concentration in one area, even when this does not fulfill the letter of the distribution requirement, may petition to the IT office for waiver of the category requirements.

General Regulations

Satisfactory work is represented by a C average (2.00) or better. That is, the number of grade points must be at least twice the number of course credits for those courses in which a grade of A, B, C, or D has been earned.

If a student's cumulative grade point average is less than 2.00 at the conclusion of any quarter, he is placed on academic probation. Most departments review, at least once a year, their students who are on academic probation; other departments review them more frequently. Students on academic probation may be subject to drop action at the conclusion of the next quarter following, provided the grade point average does not once again come above 2.00. Departments wishing to review students on academic probation will set a time and place for such interviews. Two copies of the scholastic academic probation appeal form (form E-100) will be prepared by the college office in 105 Main Engineering Building in advance of the meeting. Following action of the department committee, the student will present one form in 105 Main Engineering Building. The department action will be considered final following a review by the assistant dean. The departmental copy of the exclusion appeal will remain in the department with its action.

All students appearing before their departmental Scholastic Standards Committee should present their grade slip or an up-to-date transcript for the quarter to the committee at the time of the conference.

All students are allowed to repeat courses in which a D grade was received

and only the last grade earned will then be used in computing the GPA for graduation purposes.

IT students taking lower division IT sequence courses must earn a grade of at least a C in order to continue in the sequence.

The Institute of Technology uses the same grading system as the other colleges on the Twin Cities campuses. That is, the grades normally used at the undergraduate level are A, B, C, D, S, N, I, and W. The Institute of Technology will compute for each of its undergraduate students what is termed a coefficient of completion. This will be computed on both a quarterly and a cumulative basis. This coefficient is computed as a ratio of the credits satisfactorily completed, divided by the total credits for which registered at the end of 2 weeks. On a quarterly basis, this coefficient of completion should be higher than .5 and on a cumulative basis it should be higher than .8. For a student whose coefficient of completion falls below the above figures, departments will be notified of such status and may take whatever action they wish in order to be of most assistance to the student.

Students wishing to cancel a course with a grade of W may do so up to study day regardless of their standing in the course at that time. Students wishing to change majors from one department to another must file a petition which will then be routed to the department which the student wishes to enter for decision on the matter. Students wishing to repeat courses in which a grade of C or better has been obtained must petition for approval.

The Bachelor's degree with professional designation will be recommended for those students with grade point averages of 2.00 or better who have completed all of the required work and have the total number of credits specified in their curricula.

Students having a grade point average of 3.50 or better for their undergraduate work within the University (excepting their last quarter's work) will be granted their degree "with high distinction."

Students having a grade point average between 3.00 and 3.49 for their undergraduate work within the University (excepting their last quarter's work) will be granted their degree "with distinction."

A student who enters with advanced standing from other colleges or universities must spend at least a year in regular daily work at the University, of which 2 quarters must be in his senior year (if he has only 1 year of residence, it must be in his senior year). He must complete 45 credits in residence. Evening class credits will not apply toward the residence requirement unless approved by petition. Credits earned through independent study are not accepted as credits-in-residence.

Prospective graduating students should go to Window 22, Morrill Hall to complete an Application for Degree approximately 1 year prior to the scheduled graduation date.

Acceptance of Transfer Credits—Credit for a course in which a grade of D has been received will be allowed in technical course sequences only if it is followed by a higher grade in a course in the sequence. Grades of D in liberal education electives and English are accepted in transferring from outside the University.

Change of Major Department—A student desiring to change his major department within IT must submit a petition requesting such a change. Forms are available in 105 Main Engineering Building. The petition must be approved by the

chairman (or his representative) of the department to which the student wishes to transfer.

A student in IT who wants to transfer to another college, school, or campus within the University must meet the requirements of the second unit. Applications for transfer should be made at the Office of Admissions and Records as far in advance as possible of the actual date of transfer. Deadlines for transfer are set by some colleges.

Fees and Expenses—University tuition, fees, and other expenses are subject to change without notice. Room and board costs in the following table are based upon average University residence hall rates.

ESTIMATED EXPENSES OF MINNESOTA RESIDENTS
(Fall, Winter, and Spring Quarters)

Tuition and fees	$ 675.00
Books and supplies	125.00
Room and board	1,200.00
Total	$2,000.00

Refunds—Students who cancel their registration before 6 weeks of any quarter have passed are entitled to refund of tuition, student services fees, and course fees on the following basis: Those who do not attend classes at all get full refund; those who cancel within the first week, get 90 percent; within the second, 80; third, 70; fourth, 60; fifth, 50; sixth, 40. After the sixth week there is no refund.

Members of reserve units activated for military service may receive full refund of tuition if credits or "incompletes" cannot be allowed.

Cancellation of courses which results in a total below 12 credits the first 6 weeks of the fall-winter-spring quarters involves a partial refund of tuition.

IV. COURSE DESCRIPTIONS

Symbols—The following symbols are used throughout the course descriptions in lieu of page footnotes:

* Courses in which it is possible for graduate students to prepare Plan B papers.

† All the courses following the dagger must be completed before credit will be granted for any quarter of the sequence.

§ Credit will not be given if the equivalent course listed after the section mark has been taken for credit.

¶ Means "concurrent registration."

‡ Means "consent of instructor is required."

△ Means "consent of division, department, or school offering course is required."

A hyphen between course numbers (3142-3143-3144) indicates a sequence course which must be taken in the order listed.

A comma between course numbers (1234, 1235, 1236) indicates a series of courses which may be entered any quarter.

Courses numbered 8000 or above are for graduate students only, except by specific permission of the dean of the Graduate School.

Class rank prerequisite (3rd year) means that no one below that rank may register for the course without specific permission from the Scholastic Standards Committee.

A prerequisite course listed by number only (prereq 5246) is always in the same department as the course being described.

Prerequisite credits listed by amount only (prereq 6 cr) mean credits which must have been earned in the same department offering the course being described.

SPECIAL INTEREST COURSES FOR IT STUDENTS

Engl 3085. TECHNICAL WRITING FOR ENGINEERS. (4 cr; prereq completion of Freshman English)
Theory and practice in technical and professional writing.

EBB 3101. ECOLOGY FOR ENGINEERS AND PHYSICAL SCIENTISTS. (4 cr, §1003, 3001, Biol 1104; not open to biology majors; prereq Math 1231)
Course for engineers and physical science students to present a scientifically sound understanding of the basis for the existence and continued existence of life on the earth.

I of T 1811. HISTORY OF ANCIENT AND MEDIEVAL SCIENCE. (4 cr)
Physics and biological sciences in antiquity and their transmission to and development in the middle ages, Egyptian and Babylonian mathematics and astronomy; the systems of Aristotle, Galen, and Ptolemy; medieval mechanics and cosmology; alchemy and astrology.

I of T 1812. HISTORY OF 16TH- AND 18TH-CENTURY SCIENCE. (4 cr)
The "scientific revolution." Copernican revolution; mechanics (Galileo and Newton); anatomy and physiology (Vesalius and Harvey); and chemistry (Lavoisier). The relations of the "new" science to the "new" philosophy and to the emerging Western industrial society.

I of T 1813. HISTORY OF 19TH- AND 20TH-CENTURY SCIENCE. (4 cr)
Development of physics, biology, chemistry, and geology. Darwin and evolution; genetics; electricity; and atomic physics. Philosophical and social issues including social Darwinism and the development of atomic weapons.

SSci 3402. ECOLOGY, TECHNOLOGY, AND SOCIETY. (4 cr)
The impact of technology on society as seen by engineers, scientists, and social scientists. The social problems associated with economic growth such as environmental consequences, the arms race, food and fertilizers, and population growth. Alternative strategies for meeting the problems.

ADDITIONAL I OF T COURSES

Experimental courses on the interaction of science and technology and society are often offered; see current *Class Schedule.*

Aerospace Engineering and Mechanics (AEM)

1001. AEROSPACE ENGINEERING ORIENTATION. (1 cr; prereq 1st qtr freshman interested in aerospace engineering)
Fundamentals of aerospace engineering practice presented by professional engineers and members of the faculty.

1005-1006. AEROSPACE SURVEY AND LABORATORY. (1 cr per qtr)
Science, engineering, and aerospace technology. Course areas and technical electives in aero curriculum. Trajectories, orbits, flight mechanics, structures, and materials. Experimental and theoretical aerodynamics. Winged atmospheric, ballistic, and space vehicles.

1015. STATICS. (4 cr; prereq Math 1231)
Vector algebra. Principles of statics. Application of the equations of equilibrium to the analysis of simple structures and machines. Statically determinate beams. Cables. Nature and influence of friction.

3016. DEFORMABLE BODY MECHANICS. (4 cr; prereq mathematics through differential equations and linear algebra)
Principles of statics; equilibrium conditions. Uniaxial loading and deformation. Stress and strain at a point. Material behavior; linear elasticity. Torsion. Bending of beams of symmetrical section.

3017. INTERMEDIATE SOLID MECHANICS. (4 cr, §3016; prereq CE 3605 or #)
Analysis of stress and strain at a point. Stress equilibrium equations. Strain-displacement equations. Stress-strain-temperature relations. Application to torsion and simple stress concentration problems.

3036. DYNAMICS. (4 cr; prereq mathematics through differential equations and linear algebra)
Review of particle dynamics. Mechanical systems and the rigid-body model. Equilibrium. Kinematics and dynamics of plane systems. Technical applications.

3092. STATICS AND MECHANICS OF MATERIALS. (4 cr; prereq Math 1231, Phys 1121; 3 lect and 2 rec periods per wk)
Forces, equilibrium, and free-body diagrams. Analysis of statically determinate, plane pin-connected trusses and frames. Graphical methods. Moment and shear distribution in beams. Bending of beams. Buckling of columns.

3093. MECHANICAL PROPERTIES OF CONSTRUCTION MATERIALS. (4 cr; prereq 3092; 3 lect and 1 lab period per wk)
Strength and deformation of metals, polymers, timber, ceramics, glass, and composites. Response to tensile, compressive, torsion, and bending loads. Environmental effects. Acoustical properties. Tests for determining mechanical properties.

5200. KINEMATICS AND DYNAMICS OF FLUID FLOW. (4 cr, §CE 3400; prereq mathematics incl vector calculus; 3 lect and 2 rec hrs per wk)
Kinematics of fluid flow including continuity equation, vorticity, circulation, velocity potential, source, and doublet. Application of Gauss's and Stokes' theorem to fluid flow. Flow about cylinder. Potential flow in two and three dimensions. Dynamics, Euler's equation, Bernoulli's equation. Aerostatics.

5201. SHOCK WAVES AND COMPRESSIBLE FLUID FLOW. (4 cr; prereq 5200; 3 lect and 2 rec hrs per wk)
Basic concepts of thermodynamics. One-dimensional steady isentropic flow. Laval nozzle. Normal and oblique shock waves and reflections. Prandtl-Meyer flow. Supersonic thin airfoil theory.

5202. INCOMPRESSIBLE BOUNDARY LAYER THEORY. (4 cr; prereq 5200; 3 lect and 2 rec hrs per wk)
Curvilinear coordinate systems, cylindrical and spherical. Viscous incompressible flow. Thin airfoil theory. Stress and strain rate. Navier-Stokes' equation. Boundary layer equation and Blasius solution. Von Karman momentum integral. Pohlhausen method. Turbulent boundary layer.

5204. INCOMPRESSIBLE POTENTIAL FLOW. (4 cr; prereq 5200 or #)
Irrotational, incompressible flows in two dimensions are solved by complex variable methods. These methods are applied to analysis of airfoils and to other motions of interest in aerodynamics.

5206. AERODYNAMICS OF LIFTING SURFACES. (4 cr; prereq 5200)
Thin airfoil theory, finite wing, aspect ratio, planform, lift distribution, effect of viscosity, the boundary layer, skin friction drag, polar diagrams, dimensional analysis, and dynamic similarity. Review of linearized supersonic theory.

5220. INTERMEDIATE INVISCID FLOW. (4 cr; prereq 5200 or #)
Motion and interaction of two-dimensional vortices. Vortex streets and wakes. Application to ground effects, biplane, wake drag. Vector potentials applied to airfoil theory. Three-dimensional flows induced by the motion of solids. Induced mass and impulsive motion.

5240. RAREFIED GAS DYNAMICS. (4 cr; prereq 5201 or #)
Elementary kinetic theory. Relationship between continuum and molecular models for gas flow. Free molecule flows. Lift, drag, and energy transfer in free molecule flows. Slip flow and temperature jump.

5241. HIGH SPEED GAS DYNAMICS. (4 cr; prereq 5201)
One-dimensional unsteady flow. Shock tube flows. Characteristics. Weak wave theory. Two-dimensional supersonic airfoil theory. Blast wave theory. Hypersonic similarity. Hypersonic flow past slender bodies with sharp leading edges. Effects of slight leading edge blunting. Resistance and drag. Viscous effects.

5242. ONE-DIMENSIONAL GAS DYNAMICS. (3 cr; prereq 5202)
Properties of normal shocks. Flows through nozzles. One-dimensional channel flow with friction and energy addition. Continuous unsteady one-dimensional flows of perfect fluids. Flows in wind tunnels and diffusers. Shock tube flows.

5270. TURBULENCE AND ATMOSPHERIC FLUID DYNAMICS. (4 cr; prereq some background in viscous flow, such as 5202 or #)
General survey of the large-scale circulation of the earth's atmosphere. Review of laboratory turbulence and application to the atmospheric boundary layer. Eckman layer. Thermal stratification. Diffusion of pollutants in the atmosphere.

5290. INTRODUCTION TO MAGNETOHYDRODYNAMICS. (4 cr; prereq 5200 or #)
Fundamental equations and concepts of magnetohydrodynamics and electrohydrodynamics. Transport of magnetic field, MHD channel flow, Alfven waves, transverse waves, and magnetogasdynamic flow over thin bodies. Steady electrohydrodynamic convection in drops and around bubbles, cellular convection.

5300. FLIGHT MECHANICS. (4 cr; prereq 5206)
Standard atmosphere, analysis of power required, the classical performance data, maximum and minimum speed, maximum rate of climb, angle of climb and glide, absolute ceiling, service ceiling of propeller and jet propelled aircraft. Static longitudinal stability, wing contribution, tail contribution, fuselage contribution, and the neutral point. Power effect and longitudinal control. Introduction to longitudinal dynamics.

5309. ROCKET AND SPACECRAFT PERFORMANCE. (4 cr; prereq 5200, 3036)
Single and multistage rocket configurations; stabilization and control by gimbal motors, vernier engines, gyros and other means. Rocket thrust, velocity, and altitude as functions of specific impulse and design parameters. Circular, elliptical, and escape trajectories about a central body; orbit determination, period of orbits and transfer orbits. Terrestrial vacuum trajectories, range, velocity, and period. Reentry trajectories, flight mechanics of shuttle aircraft.

5319. DYNAMIC STABILITY OF AEROSPACE CRAFT. (4 cr; prereq 5206 and 5430)
Static stability coefficients and derivatives about the three main axes. Equations of motion for six degrees of freedom. Decoupled equations of motion about the longitudinal axis, specific and generalized. Effect of elevator and rudder powers, stick-fixed and stick-free conditions. Ruth's discriminant. Aerospace vehicle working equations and solutions. Vehicle response to control actions.

5330, 5331. DESIGN OF AEROSPACE ELEMENTS AND SYSTEMS. (4 cr per qtr; prereq 4th yr engineer and ‡)
Interdisciplinary projects with students from other departments.

5359. AERODYNAMIC DECELERATOR PERFORMANCE. (4 cr; prereq 5200 and 3036)
Structurally integrated decelerators, reverser propellers, jet thrust reversers, retrorockets. Types of subsonic and supersonic and gliding parachutes. Aerodynamic coefficients as function of geometric and cloth porosity. Nominal and effective porosity. Aircraft antispin, brake and landing parachutes. Terrestrial and reentry trajectories, serial delivery, and recovery systems.

5360. DYNAMICS AND STRESS ANALYSIS OF AERODYNAMIC DECELERATORS. (4 cr; prereq 5200 and 3036)
Snatch force and opening shock calculations. Effects of included and apparent masses and similarity conditions. Air resistance of porous screens as function of Mach, Reynold's and Knudsen numbers. Dynamic stability of parachutes, drag and stability of two-body systems. Combinations of parachutes and retrorockets. Stress analysis and stress measurements.

5370, 5371. AERODYNAMICS OF V/STOL FLIGHT. (4 cr per qtr; prereq 5206)
Aerodynamic characteristics of the classical rotor are considered. Combinations of rotor-wing and direct thrust-wing configurations are analyzed for high-speed V/STOL aircraft. The jet flap, boundary layer control, and ground effect machines are also considered.

5410. INTRODUCTION TO CELESTIAL MECHANICS. (4 cr; prereq 3036 or ‡)
Review of central force motion, the two-body problem, classical and modern methods of orbit determination, celestial coordinates, orbital elements and Eulerian angles, transfer orbits based on a two-body model, introduction to the three-body problem.

5430. INTRODUCTION TO DYNAMICAL SYSTEMS. (4 cr; prereq 3036)
Modeling of simple mechanical, hydraulic, and electromechanical systems, transfer functions, concepts of stability and free vibrations, response to periodic and simple nonperiodic inputs, elementary concepts in feedback control.

5435. INTRODUCTION TO RANDOM VIBRATION THEORY. (3 cr; prereq 5430)
Statistical descriptions of response of single-degree-of-freedom damped vibrators to nondeterministic forces. Effects of damping and frequency spectra. Measurable quantities. Response of two-degree-of-freedom systems. Impedance methods. Response of linear continuous systems. Comparison of higher approximations, descriptions of damping, modal coupling, and spectrum shaping. Acoustic excitation. Fatigue failure criteria.

5438. INTERMEDIATE DYNAMICS. (4 cr; prereq 3036)
Three-dimensional Newtonian mechanics, kinematics of rigid bodies, dynamics of rigid bodies, analytical mechanics, generalized coordinates, holonomic constraints, Lagrange's equations, application of Lagrange's equations to systems of technological interest.

5440. INTERMEDIATE DYNAMICAL SYSTEMS. (4 cr; prereq 5430)
Modeling of multidegree of freedom systems in vector-matrix form, concept of stability and free vibrations, forced and unforced response of mechanical systems with conservative, dissipative, and gyroscopic forces, response to arbitrary forcing functions, intermediate concepts in feedback control.

5515. AEROSPACE STRUCTURES I. (4 cr; prereq 3016)
Bending of slender, reinforced, thin-wall beams. Shear flow, shear center, thermal stresses. Torsion of slender members; membrane analogy; open and closed thin-wall sections. Energy methods. Bending of thin plates. Buckling of columns and plates. Matrix methods of deflection analysis.

5516. AEROSPACE STRUCTURES II. (4 cr; prereq 5515)
Application of matrix methods to analysis of flight structures. Computer programming and solution of structural problems. Stability analysis of thin-wall columns, plates, and stiffened shells; buckling. Introduction to finite-element methods.

5517. APPLIED ELASTICITY. (4 cr; prereq 3016)
Bending and buckling of beams and bars. Energy methods. Torsion of thin-walled sections; combined bending and torsion. Axisymmetric problems. Introduction to plastic bending, torsion, and buckling.

5550. MECHANICAL BEHAVIORS OF SOLIDS. (4 cr; prereq 3016; 3 lect and 1 lab period per wk)
Structure of metals and polymers. Plastic deformation of crystalline and amorphous material. Time-dependent deformation. Composites. Response to tensile, compressive, torsion, and bending loads. Theories of failure under combined stresses. Response to dynamic loading. Tests for mechanical properties.

5551. FATIGUE AND FRACTURE MECHANICS. (4 cr; prereq 5550 or MatS 5301 or ♯; 3 lect and 1 lab period per wk)
Theories of strength and mechanical failure. Brittle, ductile, and transitional modes of fracture. Fracture toughness. Time-dependent fracture. Fatigue crack nucleation and propagation. Effects of active and passive environments. Stress corrosion.

5580. MECHANICS OF ELASTIC SOLIDS I. (4 cr; prereq 3016)
Kinematics of deformation and strain; strain invariants; compatibility. Stress; equations of equilibrium and motion; stress invariants. Stress-strain-temperature relations; isotropy; strain energy. Fundamental boundary value problems of elasticity and thermoelasticity; uniqueness. Curvilinear coordinates. Simple exact solutions. Saint Venant problems of extension bending, torsion, and flexure.

5581. MECHANICS OF ELASTIC SOLIDS II. (4 cr; prereq 5580)
Plane theories; plane strain; generalized plane stress; Airy's stress function. Example problems; stress concentration; half-plane; long cylinders; layered media. Thermoelasticity in two dimensions. Elastodynamics; Lame separation. Waves; F and S waves; boundary reflection and refraction; Rayleigh waves. Vibration of bounded regions.

5582. ENERGY METHODS IN SOLIDS. (4 cr; prereq 5580)
Elements of variational calculus. Virtual work. Reciprocal theorem. Energy principles in elasticity; potential energy; complementary energy; principle of least work; Prager-Synge method. Variational formulation of bending and buckling of beams and plates. Direct methods of the calculus of variations; Rayleigh-Ritz; Galerkin; error estimates. Energy principles of elastodynamics. Waves and vibrations in bounded media.

5585. MECHANICS OF INELASTIC SOLIDS. (4 cr; prereq 5580 or ♯)
Topics to include basic concepts and applications of viscoelastic and/or plastic materials. Linear viscoelastic behavior, linear viscoelastic constitutive assumptions; viscoelastic stress analysis; problems of quasi-static and sinusoidal nature; correspondence principle. Plasticity; yield conditions and flow laws for perfect plastic and strain-hardening materials; limit analysis theorems; simple structures. Applications to trusses, beams, frames, plates, and torsion of cylinders.

5645, 5646. AEROMECHANICS LABORATORY I, II. (3 cr per qtr; prereq 5200, 3016; 4 lab hrs per wk)
Subsonic and supersonic wind tunnel experiments including lift and drag measurements, flow-visualization methods, pressure-measuring techniques and boundary-layer measurements. Viscous-flow experiments. Vibrations. Analog methods. Rheological and strength properties of materials and structures.

5647. AEROMECHANICS LABORATORY PROJECTS. (3 cr; prereq 5200 and ♯; 4 lab hrs per wk)
Individual experimental projects of a research nature.

5649. EXPERIMENTAL MECHANICS I. (2 cr; prereq 3016; 1 lect and 2 lab hrs per wk)
Strain gages. Photoelasticity. Experimental stress analysis. Deformation of beams and columns. Torsion, tension, and shear tests.

5650. AEROELASTICITY I. (4 cr; prereq 5206)
Static aeroelastic phenomena, torsional divergence of a lifting surface, control surfaces reversal and elastic efficiency. Effects of elastic deformations on stability, aeroelastic twisting of propeller blades and rotary wings, theory of lifting surface flutter, problems of gust response and buffeting, scaling of aeroelastic force models.

5680. RANDOM PROCESSES. (3 cr; prereq Math 5211 or equiv or ♯)
Probability densities, averages, correlations, power spectra; interrelations. White noise. Gaussian processes. Random walk problems. Wiener-Hermite functionals for nonlinear processes. Examples for discrete systems and fluid systems.

5687. INTRODUCTION TO ACOUSTICS AND ENVIRONMENTAL NOISE. (4 cr; prereq Phys 1291, Math 3221 or equiv; 3 lect and 1 lab period per wk)
Derivation of the wave equation, plane wave solution, transmission and reflection at boundaries, resonators and mufflers, three-dimensional wave propagation, properties of environmental noise sources, hearing and perception of sound, acoustic properties of rooms, laboratory experience in sound and noise measurements and noise control techniques.

5688. INTERMEDIATE ACOUSTICS. (4 cr; prereq 5687)
Wave propagation in inhomogeneous media with application to atmospheric and underwater acoustics, propagation in ducts, Kirchoff solution to the inhomogeneous wave equation, radiation from moving sources including rotating machinery.

5689. SPECIAL TOPICS IN ACOUSTICS. (4 cr; prereq 5688)
Selected topics of current interest to students and staff.

5800, 5801, 5802. PROBLEMS IN MECHANICS AND MATERIALS. (0-3 cr per qtr; prereq ♯; faculty sponsor required prior to regis)
Short-duration, individual research problems, literature studies, and reports.

5810, 5811, 5812. PROBLEMS IN FLUID MECHANICS. (0-3 cr per qtr; prereq ♯; faculty sponsor required prior to regis)
Investigation of analytical and experimental problems approved by faculty member. Undergraduate thesis.

5838, 5839. SUMMER ENGINEERING EMPLOYMENT. (1-3 cr per qtr; prereq ♯, completion of 3rd yr and ♯ prior to regis)
Written report based on summer work in an engineering field (not less than 360 hours per summer).

5840-5841-5842-5843. INDUSTRIAL ASSIGNMENT. (2 cr per qtr; prereq regis in engineering intern program)
Engineering intern industrial laboratory. A formal technical report, covering the work during the industrial assignment, is required.

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8001, 8002, 8003. SEMINAR: AEROSPACE ENGINEERING AND MECHANICS

8201. FOUNDATIONS OF FLUID MECHANICS

8202, 8203. INVISCID FLUID MECHANICS

8207. INSTABILITY OF FLOW OF VISCOUS FLUIDS

8208. NONLINEAR THEORIES OF HYDRODYNAMIC STABILITY

8209. ROTATING FLUIDS

8210-8211. VISCOUS FLUID MECHANICS

8216. THEORY OF TURBULENCE

8217. APPLICATIONS OF TURBULENCE THEORY

8230-8231-8232. TRANSONIC AND HYPERSONIC FLOW

8240. PERTURBATION METHODS IN FLUID MECHANICS

8250-8251-8252. MAGNETOFLUIDDYNAMICS

8280. INTERNAL RAREFIED GAS FLOW

8285-8286. SELECTED TOPICS IN RAREFIED GAS DYNAMICS

8410. DYNAMICAL SYSTEMS I: CLASSICAL MECHANICS

8411. DYNAMICAL SYSTEMS II: LINEAR SYSTEMS

8412. DYNAMICAL SYSTEMS III: NONLINEAR SYSTEMS

8413-8414-8415. DYNAMICAL SYSTEMS IV, V, VI: ADVANCED TOPICS

8510. CONTINUUM MECHANICS I

8511, 8512. CONTINUUM MECHANICS II, III

8522. PERFECTLY PLASTIC SOLIDS

8523. SPECIAL TOPICS IN PLASTICITY

8527. THEORY OF ELASTIC STABILITY

8541-8542. THEORY OF VISCOELASTICITY

8545. LINEAR VISCOELASTICITY

8546. NONLINEAR VISCOELASTICITY

8570. FRACTURE MECHANICS

8585, 8586, 8587. ADVANCED TOPICS IN CONTINUUM MECHANICS

8590. THEORY OF PLATES AND SHELLS

8591. ADVANCED THEORY OF SHELLS I

8592. ADVANCED THEORY OF SHELLS II

8594. ELASTICITY I

8595. ELASTICITY II

8596. ELASTICITY III

8606. NUMERICAL METHODS IN MECHANICS

8607. ADVANCED NUMERICAL METHODS IN MECHANICS

8800, 8801, 8802. SELECTED TOPICS IN MECHANICS AND MATERIALS

8810, 8811, 8812. SELECTED TOPICS IN FLUID MECHANICS

Agricultural Engineering (AgEn)

1060. AGRICULTURAL ENGINEERING ORIENTATION. (1 cr; S-N only; 2 hrs per wk)
Introduction to agricultural engineering practice by lecture, reading, demonstration, and classroom discussion. Identification of professional opportunities and responsibilities.

1070. INTRODUCTORY AGRICULTURAL ENGINEERING. (4 cr; prereq Math 1231, Phys 1271; 2 lect and 4 lab hrs per wk)
Interrelation of basic biological and environmental engineering and management requirements for food production. Examples in several fields of agricultural engineering are solved by use of digital and analog models. Computer experience. Report writing.

3050. SOIL-PLANT RELATIONS IN AGRICULTURAL ENGINEERING. (4 cr; prereq AEM 3016 or ¶AEM 3016; 3 lect and 3 lab hrs per wk)
Interrelation of the soil-plant system and engineering and management requirements. Plant structure. Growth processes. Soil-plant environment. Energy and water balance. Limiting factors. Mechanical and hydraulic properties of soil profile, moisture relations; strength parameters for structural and mechanical design.

3060. SIMULATION AND EVALUATION. (4 cr; prereq Math 3211 or ♯; 4 lect hrs per wk)
Introduction to probability and elementary statistics with application to problems in agricultural engineering. Digital simulation and modeling with application to agricultural engineering problems. Linear programming with applications. Engineering economics and cost-benefit analysis.

5050. INTERN REPORTS. (1 cr per qtr)
Required of students in the engineering intern program during the employment periods.

5060. PROCESSING. (4 cr; prereq 3060, ME 5342 or ♯; 3 lect and 3 lab hrs per wk)
Size reduction, cleaning, and conveying of agricultural products. Properties of air, water vapor, and biological materials. Engineering principles of moisture and heat transfer applied to drying of grain crops. Theory and application of refrigerated and controlled atmosphere storage.

5070. AUTOMATIC CONTROL AND INSTRUMENTATION. (4 cr; prereq 3050, EE 3000; 2 lect and 4 lab hrs per wk)
Control of machines and processes. Linear feedback control. Linking of physical and biological control systems. Instrumentation for control systems and industrial development studies.

5081, 5082, 5083, 5084. DESIGN. (4 cr per qtr; prereq sec qtr sr status; 1 lect and 6 lab hrs per wk)
An engineering design project in the student's interest area or multi-area, integrating previous work and covering the whole range of the design process from conceptualization through preparation of the project report.
5081. Power and Machinery
5082. Soil and Water
5083. Structures and Environment
5084. Food Engineering

5130. FOOD ENGINEERING I. (4 cr; prereq knowledge of growth and survival of microorganisms, food spoilage and poisoning, food chemistry, thermodynamics of mixtures, 5060 or ¶5060 or ♯; 4 lect hrs per wk)
Fundamental requirements for handling food products. Separation processes in the food industry. Dehydration and storage of foods.

5140. FOOD ENGINEERING II. (4 cr; prereq FSN 3120, chemistry of basic food components and their reactions, introduction to electromagnetics or ♯; 3 lect and 3 lab hrs per wk)
Engineering principles of thermal processing of food, pasteurization, heat exchange, sterilization, baking, and microwave heating. Sanitation and microbiological aspects of food engineering.

5330. AGRICULTURAL MACHINERY. (4 cr; prereq 3050, 3060, ME 3201, 3203 or equiv; 3 lect and 3 lab hrs per wk)
Principles of operation and performance characteristics of agricultural machines. Operating forces on selected machine components. Control systems, design for operator convenience and safety. Machinery selection and management. Design of machine elements and assemblies. Motion analysis.

5340. AGRICULTURAL TRACTORS. (4 cr; prereq 3050, ME 3303 or equiv; 3 lect and 3 lab hrs per wk)
Tractor engines. Cycle analysis, combustion fuels, and accessory systems. Chassis mechanics. Hitches and implement control systems. Power transmission systems. Tractor performance.

5390. PROBLEMS IN AGRICULTURAL ENGINEERING—POWER AND MACHINERY. (2-5 cr per qtr; prereq sr status and ♯)

5540. EROSION CONTROL, WATERSHED ENGINEERING. (4 cr; prereq 3050, 3060, CE 5401; 3 lect and 3 lab hrs per wk)
Measurement and mechanics of watershed runoff and soil erosion. Estimating peak runoff, soil losses, and sediment yields. Environmental effects. Principles of small watershed planning for flood control, water storage, and sediment control. Hydraulic design of graded and storage type terraces, grass waterways, diversions, and erosion control structures.

5550. DRAINAGE AND IRRIGATION ENGINEERING. (4 cr; prereq 3050, 3060, CE 5401; 3 lect and 3 lab hrs per wk)
Flow of water through agricultural soils. Irrigation and drainage requirements, salinity control, evapotranspiration, water supply development and control. Conveyance of drainage and irrigation waters. Considerations for design, layout, and construction of irrigation and drainage systems. Institutional, environmental, and economic aspects of soil moisture control.

5590. PROBLEMS IN AGRICULTURAL ENGINEERING—SOIL AND WATER. (2-5 cr per qtr; prereq sr status and ♯)

5730. AGRICULTURAL STRUCTURES DESIGN. (4 cr; prereq 3050, AEM 3016; 3 lect and 3 lab hrs per wk)
Building types and materials for agricultural production. Snow and wind loads. Loads associated with agricultural materials in storage. Codes and standards. Foundations and footings. Sanitation. Determinant analysis and indeterminate concepts. Computer-aided design.

5740. ENVIRONMENTAL CONTROL FOR AGRICULTURAL PRODUCTION. (4 cr; prereq 3050, 3060, ME 5603; 3 lect and 3 lab hrs per wk)
Ventilation, insulation, and condensation control in enclosed plant and animal production structures. Biological constraints upon the system. Temperature, humidity, light, and contaminants, e.g., dust, noxious gases, and pathogens. Simulation of weather phenomena for predicting of environmental conditions.

5790. PROBLEMS IN AGRICULTURAL ENGINEERING—STRUCTURES AND ENVIRONMENT. (2-5 cr; prereq sr status and ‡)

5910. AGRICULTURAL WASTE MANAGEMENT ENGINEERING I. (4 cr; prereq upper division...3050, 3060; 3 lect and 3 lab hrs per wk)
Sources and characteristics of agricultural wastes including animal manures, crop residues, sediments, processing wastes, and domestic wastes. Effects on the environment. Sanitary collection, storage, treatment, and disposal. Utilization of liquid and solid wastes. Nonurban water supply and quality.

5920. AGRICULTURAL WASTE MANAGEMENT ENGINEERING II. (4 cr; prereq 5910; 3 lect and 3 lab hrs per wk)
Design of systems for the collection, storage, treatment, utilization, and disposal of animal wastes.

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8100. SEMINAR

8140. AGRICULTURAL ENGINEERING SIMILITUDE

8190/8191/8192. ADVANCED PROBLEMS AND RESEARCH

8500. HYDROLOGIC MODELING—SMALL WATERSHEDS

8700. MOISTURE AND HEAT TRANSFER

Architecture (Arch)

1001f. ENVIRONMENTAL DESIGN: MAN AND ENVIRONMENT. (4 cr, §LA 1001)
Exploration of interaction of man and his environment using the disciplines of natural and social sciences and the arts as resource background for readings, lecture, discussion, and workshop sessions.

1002w. ENVIRONMENTAL DESIGN: TOOLS AND PROCESSES. (4 cr, §LA 1002; prereq 1001)
Examination of nature and effects of various tools and processes of environmental change ranging from buildings and landscapes to economic policies, climate, and myths. Readings, lectures, discussion, and workshop sessions.

1003s. ENVIRONMENTAL DESIGN: IMPLEMENTATION AND EVALUATION. (4 cr, §LA 1003; prereq 1002)
Design projects, discussions, and readings exploring personal abilities to implement and evaluate environmental change.

1021f. HISTORY OF ENVIRONMENTAL DEVELOPMENT: ARCHITECTURE. (4 cr, §LA 1021; 4 lect hrs per wk)
Introduction to architecture, philosophy, and principles of architecture as an art; survey of architectural history with emphasis upon development of contemporary architecture from its roots in the 19th century until the present time.

1022w. HISTORY OF ENVIRONMENTAL DEVELOPMENT: LANDSCAPE ARCHITECTURE. (4 cr, §LA 1022; prereq 1021; 4 lect hrs per wk)
Introduction to landscape architecture. Discussions focused on investigating those forces and individuals that shaped the form of landscape in 19th- and early 20th-century America.

1023s. HISTORY OF ENVIRONMENTAL DEVELOPMENT: PLANNING. (4 cr, §LA 1023; prereq 1022; 4 lect hrs per wk)
Introduction to urban planning. Survey course dealing with rise and history of cities as centers of civilization. Collaboration among various disciplines for creating better urban environment and improving the quality of human life in cities.

1041-1042-1043. ART FOR ARCHITECTURE STUDENTS. (2 cr per qtr)
Freehand drawing from live models. Emphasis is given to the development of skills in accurate delineation. Various techniques and media are employed.

3061-3062. BUILDING SYSTEMS. (5 cr per qtr; 4 lect hrs per wk)
Building systems, subsystems, and components; principles of structural theory; materials and methods used in building; new and developing technologies.

3064-3065. ENVIRONMENTAL MANAGEMENT AND CONTROL. (5 cr per qtr; prereq 3062; 4 lect hrs per wk)
Environmental-mechanical considerations including comfort technology, space habitability, climate, psychometrics, control and management systems; waste management including plumbing systems and waste disposal techniques. Electrical systems, energy, power distribution and machinery; lighting systems, physiology of seeing, light sources and control; spatial acoustics, noise barriers, absorption.

3067. INTEGRATED DESIGN SYSTEMS. (4 cr; 2 lect and 2 seminar hrs per wk)
Introduction to integrated design systems; systems approach to defining environmental problems and managing multidisciplinary inputs; analysis and evaluation of alternative solutions; computer graphics including elements of equipment and interactive modes of use.

3081-3082-3083. ARCHITECTURAL DESIGN. (6 cr per qtr; prereq 2nd yr for IT students, jr for CLA students and △; 18 lab hrs per wk)
Basic exercises in composition of line, form, proportion, color, and texture. Elements of architectural design. Architectural drawing; model making; design process.

3091-3092-3093. ARCHITECTURAL DESIGN. (6 cr per qtr; prereq 3083; 18 lab hrs per wk)
Architectural problems with emphasis on development of structures as an integral part of design; site planning; design process.

3970. DIRECTED STUDY. (Cr ar; prereq #)
Areas of study useful to individual program objectives not available in regular course offerings.

5051. ANCIENT ARCHITECTURE. (4 cr; prereq 1021; 3 lect and 1 seminar hrs per wk)
History of development of architecture and urban design in Egypt, Mesopotamia, Crete, Mycenae, and Classic Greece and Rome until the advent of Christianity.

5052. EARLY MEDIEVAL ARCHITECTURE. (4 cr; prereq 1021; 3 lect and 1 seminar hrs per wk)
History of the development of architecture and urban design during Early Christian, Byzantine, Islamic, Carolingian, and Romanesque periods in the Near East and western Europe until A.D. 1150.

5053. GOTHIC ARCHITECTURE. (4 cr; prereq 1021; 3 lect and 1 seminar hrs per wk)
History of development of architecture and urban design in western Europe from A.D. 1150 until 1400.

5054. RENAISSANCE AND BAROQUE ARCHITECTURE. (4 cr; prereq 1021; 3 lect and 1 seminar hrs per wk)
History of development of architecture and urban design in Italy, Spain, France, Germany, and the low countries from 1400 until the French Revolution.

5055. ENGLISH AND EARLY AMERICAN ARCHITECTURE. (4 cr; prereq 1021; 3 lect and 1 seminar hrs per wk)
Pre-Columbian civilizations and development of architecture and urban design in America and England from 1500 until the Civil War.

5056. MODERN ARCHITECTURE. (4 cr; prereq 1021; 3 lect and 1 seminar hrs per wk)
History of development of architecture and urban design from early 19th-century sources in Europe and America until the present time.

5057. ASIAN ARCHITECTURE. (4 cr; 3 lect and 1 seminar hrs per wk)
History of development of traditional architecture and urban design of southwest and east Asia.

5101, 5102, 5103. TUTORIAL WORK IN HISTORY OF ARCHITECTURE. (2 cr per qtr; prereq 5056 or ♯; 1 conf and 5 research hrs per wk)
Reading and written reports on special historical problems.

5104. SEMINAR: EUROPEAN ARCHITECTURE. (3 cr; prereq 5056 or ♯; 3 seminar hrs per wk)
Contemporary architecture from the beginning of modern movement until the present time with specific emphasis upon the contributions of August Perret, Peter Behrens, Walter Gropius and the Bauhaus, Le Corbusier, and the early work of Mies van der Rohe.

5105. SEMINAR: SCANDINAVIAN ARCHITECTURE. (3 cr; prereq 5056 or ♯; 3 seminar hrs per wk)
Survey of Scandinavian architectural history with emphasis upon the origin and development of modern architecture in Denmark, Finland, Norway, and Sweden.

5106. SEMINAR: AMERICAN ARCHITECTURE. (3 cr; prereq 5056 or ♯; 3 seminar hrs per wk)
Contemporary architecture in the United States from the period of Henry Hobson Richardson until the present time and including the specific contributions of Louis H. Sullivan, Frank Lloyd Wright and his "Prairie School" contemporaries, Eliel and Eero Saarinen, and the later works of Walter Gropius and Mies van der Rohe. Field trip.

5111-5112-5113. ARCHITECTURAL DESIGN. (6 cr per qtr; prereq 3093; 18 lab hrs per wk)
Advanced architectural problems of complex requirements, involving thorough study and detailed solution; electrical and mechanical equipment as well as structure as an integral part of design; research techniques and design process. Individual effort and group collaboration.

5115-5116. STRUCTURE AND FORM IN ARCHITECTURE. (4 cr per qtr; prereq AEM 3092; 2 lect and 3 seminar hrs per wk)
Form as an interface between programmatic requirements for environmental change and the physical means available to the architect; concentration on physical parameters of statics, mechanics of solids, and three-dimensional manipulation of material to arrive at logical solutions for given problems of enclosing space; architectural morphology covered through contemporary and ancient examples and experimental work on models; modular and proportional relationships.

5121-5122. ARCHITECTURAL DESIGN. (9 cr per qtr; prereq 5113 and CE 5061; 27 lab hrs per wk)
Building design and development in the urban context. Individual and collaborative effort; survey and analysis of urban problems, reporting and preparation of large-scale proposals; design process.

5123. ARCHITECTURAL THESIS. (12 cr; prereq 5122, submission of a definitive thesis program during qtr prior to thesis and 800 hrs of practical experience; 36 lab hrs per wk)
Individual choice, study, and solution of an architectural problem to demonstrate proficiency in all phases of design.

5126. PROFESSIONAL PRACTICE. (4 cr; prereq 2nd-yr design; two 2-hr seminars per wk, field trips)
Relations of architect to clients, contractors, and fellow practitioners; procedures of architectural practice, preparation of contract documents.

5130. PLANNING: THE DEVELOPMENT OF URBAN FORM. (3 cr; prereq ♯; hrs ar)
Physical development of urban place from early Middle East urban revolution to the Industrial Revolution, as a manifestation of the changes in underlying social, political, and economic forces as well as planning theories, if any, to which they gave rise.

5134-5135-5136. PLANNING. (3 cr per qtr; prereq ♯)
Tutorial work in planning and research.

5137. PLANNING: URBAN FUNCTION AND STRUCTURE. (4 cr; prereq ♯)
Exploration of economic, technological, and social factors which underlie the location, distribution, and internal structure of urban settlements. Quantitative and qualitative analysis of social, economic, and physical problems or consequences of contemporary urbanization.

5138. PLANNING: THEORY AND METHODOLOGY. (4 cr; prereq 5137 or ‡)
Logic of a planning process as a method of decision making. Formulation of goals and evaluation of alternative courses of action, standards, and requirements for specific planning objectives (housing, transportation, and community facilities). Legal, administrative, and fiscal devices for plan implementation. The place of planning function in government and the role of citizens and private groups.

5139. PLANNING. (4 cr; prereq 5138 or ‡)
Definition of problems of housing, transportation, and other subsystems of urban services. Evaluation of society's goals, private efforts and public programs designed to meet the needs in these areas. The role of technology as it affects problems and solutions.

5150. INSTITUTIONAL PLANNING. (2 cr; prereq 5113 and ‡)

5151, 5152, 5123. THEORY OF ARCHITECTURE. (2 cr per qtr; prereq ‡)
Architecture as seen in a philosophical and theoretical context.

5170. CITYSCAPE. (3 cr; prereq 5093 or ‡; hrs ar)
The city and its components as aesthetic elements. An examination of factors which have helped to generate urban form.

5171, 5172. URBAN FORM. (3 cr per qtr; prereq 5113 and 5138)
Principles and techniques involved in city design.

5970. DIRECTED STUDY. (Cr ar; prereq ‡)
Areas of study useful to individual program objectives not available in regular course offerings.

FOR GRADUATE STUDENTS ONLY

8201, 8202, 8203. SPECIAL RESEARCH IN ARCHITECTURAL HISTORY

8231, 8232, 8233. PLANNING

8251, 8252, 8253, 8254, 8255, 8256. ARCHITECTURAL DESIGN

8261, 8262, 8263. SELECTED PROBLEMS IN ARCHITECTURE

8271, 8272, 8273, 8274, 8275, 8276. PROBLEMS IN CITY AND COMMUNITY DESIGN

Astronomy (Ast)

1011. DESCRIPTIVE ASTRONOMY. (5 cr, §1021)
Survey of what is known about the sun, the moon, the planets and their motions; description of the constellations and the stellar universe to which the sun belongs. This course is completely nonmathematical.

1021. INTRODUCTION TO ASTRONOMY. (5 cr, §1011; prereq high school trigonometry and physics or chemistry)
Survey of solar system, stars, galaxies, and cosmology. A more mathematical and physical discussion than Ast 1011.

3051. INTRODUCTION TO ASTRONOMY AND ASTROPHYSICS. (4 cr; prereq 1 yr calculus and Phys 1106 or 1291, or ‡)
A survey of the known facts about the solar system, galaxy, and extragalactic universe. Discussion of the manner in which the information is obtained and some of the conclusions that can be inferred from these observations.

5161. ASTROPHYSICS OF DIFFUSE MATTER. (4 cr; prereq 3051 and Phys 3511 or ‡)
Diffuse matter in the solar system, interstellar and extragalactic space; the radiation field in these environments. Gaseous nebulae, radio astronomy and nonthermal radio sources, cosmic rays, some aspects of cosmology.

5162. ASTROPHYSICS OF CONDENSED MATTER. (4 cr; prereq 3051 and Phys 3511 or ‡)
The luminosities, temperatures, masses, and densities of stars; their mechanisms for energy generation. The chemical composition of stars and the probable course of stellar evolution.

Chemical Engineering (ChEn)

5001. MATHEMATICAL METHODS IN CHEMICAL ENGINEERING AND MATERIALS SCIENCE. (2 cr; 2 lect and 1 rec hrs per wk)
Computer programming with applications to chemical, physical, and engineering problems.

5101. PRINCIPLES OF CHEMICAL ENGINEERING. (4 cr; 3 lect and 2 rec hrs per wk) Staff
Material and energy balances applied to chemical engineering systems.

5102. PRINCIPLES OF CHEMICAL ENGINEERING. (4 cr; prereq 5101; 3 lect and 2 rec hrs per wk) Staff
Fluid dynamics and its applications to chemical engineering unit operations.

5103. PRINCIPLES OF CHEMICAL ENGINEERING. (4 cr; prereq 5102; 3 lect and 2 rec hrs per wk) Staff
Heat and mass transfer and its applications to chemical engineering unit operations.

5104. UNIT OPERATIONS AND SEPARATION PROCESSES. (4 cr; prereq 5101; 3 lect and 2 rec hrs per wk) Staff
Absorption, extraction, distillation, stagewise, and continuous separations.

5201. THERMODYNAMICS AND MATERIAL STATES. (4 cr; 3 lect and 2 rec hrs per wk) Staff
Principles of thermodynamics applied to closed and open systems and to equilibrium states of homogeneous and heterogeneous substances, gases, liquids, and solids.

5202. CHEMICAL ENGINEERING THERMODYNAMICS AND KINETICS. (4 cr; prereq 5201; 3 lect and 2 rec hrs per wk) Staff
Chemical equilibrium and chemical kinetics applied to chemical engineering systems.

5301. CHEMICAL REACTOR ANALYSIS. (4 cr; prereq 5202; 3 lect and 2 rec hrs per wk) Staff
Principles of reactor design for homogeneous and heterogeneous reactions. Analysis of reactors from a kinetic and thermodynamic point of view.

5401-5402-5403. CHEMICAL ENGINEERING LABORATORY. (2 cr per qtr; 4 lab and 1 lab conf hrs per wk)
Applications of unit operations; principles of fluid flow, heat and mass transfer; experiments and reports.

5501. PROCESS EVALUATION AND DESIGN. (4 cr; prereq 4th yr or ‡; 3 lect and 3 design lab hrs per wk) Staff
Dynamics of chemical engineering industries, economics of process evaluation, bases for cost estimations. Plant designs prepared and compared with actual installations. Special applications of unit operations, reaction kinetics, and thermodynamics.

5502. PROCESS EVALUATION AND DESIGN. (2 cr; prereq 5501; 4 design lab and 1 lab conf hrs per wk) Staff
(See ChEn 5501) Process design projects.

5601. PROCESS CONTROL. (4 cr; prereq 4th yr or ‡; 3 lect and 1 rec or 3 lab hrs per wk)
Theory and application of instrumentation and control with particular emphasis on application to the chemical industry, including analytical methods.

5603. ADVANCED PROCESS CONTROL. (4 cr; prereq 5601; 3 lect and 3 lab hrs per wk)
(Continuation of ChEn 5601) Additional methods for the analysis and design of process control systems.

5701-5702-5703. NUCLEAR REACTOR DESIGN. (3 cr per qtr; prereq ‡; 3 lect hrs per wk) Isbin
An engineering approach to the development and application of nuclear reactor theory, including basic nuclear chemistry and physics, mathematical developments and special techniques, design, operation, and control of homogeneous and heterogeneous reactors, and nuclear reactor economics. Laboratory credit available.

5751-5752-5753. BIOLOGICAL ENGINEERING ANALYSIS. (3 cr per qtr; prereq ‡; 3 lect hrs per wk) Fredrickson, Keller, Swanson
Modeling and analysis of biosystems. Thermodynamics, transport and transfer, biochemical reactions, growth and death processes are discussed from both deterministic and probabilistic viewpoints.

5754-5755. BIOCHEMICAL ENGINEERING. (4 cr per qtr; prereq 5103 or ‡; 3 lect hrs per wk) Tsuchiya, Valentas
Biochemical engineering of industrially important biological materials. Microbiological, biochemical, chemical, and engineering considerations of these systems and their industrial processing.

5901. CHEMICAL PROCESS LABORATORY. (2 cr; prereq 5301)
Applications of principles covered in ChEn 5301 in pilot or semiplant laboratory.

5902, 5903, 5904, 5905. SPECIAL PROBLEMS. (Cr ar; 1 conf hr per wk, lab hrs ar)
Investigations in chemical engineering. Library or laboratory research.

FOR GRADUATE STUDENTS ONLY

8001, 8002, 8003. PHYSICAL RATE PROCESSES AND TRANSFER OPERATIONS

8004. PHYSICAL RATE PROCESSES

8005. PHYSICAL RATE PROCESSES

8101. INTERMEDIATE FLUID MECHANICS

8102. PROBLEMS IN FLUID MECHANICS

8103. TENSORS AND FIELD THEORY WITH APPLICATIONS TO CONTINUUM MECHANICS

8104. BOUNDARY AND INTERFACE MECHANICS

8105. PRINCIPLES AND APPLICATIONS OF RHEOLOGY

8106. ADVANCED TOPICS IN FLUID MECHANICS AND TRANSPORT PROCESSES

8201-8202-8203. ADVANCED MATHEMATICS FOR CHEMICAL ENGINEERS

8301-8302. ADVANCED CHEMICAL ENGINEERING THERMODYNAMICS

8401. CHEMICAL REACTION KINETICS—KINETICS OF HOMOGENEOUS REACTIONS

8402. CHEMICAL REACTION KINETICS—SURFACE CHEMISTRY

8403. CHEMICAL REACTION KINETICS—ADVANCED TOPICS

8500. INTERMEDIATE CHEMICAL REACTOR ANALYSIS

8501-8502-8503. CHEMICAL RATE PROCESSES AND REACTOR DESIGN PRINCIPLES

8601-8602-8603. MOLECULAR THEORY OF TRANSPORT PROCESSES

8701. ANALYSIS OF CHEMICAL ENGINEERING PROBLEMS

8702. ADVANCED TOPICS IN CHEMICAL ENGINEERING

8801-8802-8803. SEMINAR

8850. GENERAL SURVEY OF CHEMICAL ENGINEERING

8901, 8902, 8903. RESEARCH IN CHEMICAL ENGINEERING

Chemistry (Chem)

Note—Each student must present a deposit card for admission to laboratory sections. See Deposit Cards section of *Class Schedule* for details.

1004-1005. GENERAL PRINCIPLES OF CHEMISTRY. (5 cr per qtr, §1014 or §1031-1032, †1004-1005; primarily for nonchemistry majors; prereq predicted mathematics GPA 1.90 on ACT, Math 0009 or college course in algebra...4 yrs high school mathematics and high school chemistry recommended; 4 lect, 1 rec, and 3 lab hrs per wk)
Introduction to chemistry from the standpoint of atomic structure; periodic properties of elements and compounds derivable from structural considerations; laws governing behavior of matter, theories of solutions, acids, bases, and equilibria.

1006. PRINCIPLES OF SOLUTION CHEMISTRY. (4 cr; prereq 1005 or 1032; 3 lect and 4 lab hrs per wk; $4 lab fee)
Lecture and laboratory work is related to chemistry of selected cations and anions. Detection methods include spectrophotometric and potentiometric as well as chromatographic procedures. Included in the program of metal ion studies are systematics; acid-base principles; influence on the environment; importance in biological systems; formation and stereochemistry of complexes.

1014. GENERAL PRINCIPLES OF CHEMISTRY. (4 cr, §1004, §1031; primarily for engineering majors, sophomores and above; prereq Phys 1210-1215, 1220-1225 or ‡; 3 lect, 2 lab, 1 rec hrs per wk)
Fundamental principles of chemistry. A terminal course.

1031. GENERAL PRINCIPLES OF CHEMISTRY. (5 cr, §1004, 1014; primarily for chemistry and chemical engineering majors; prereq 4 yrs high school mathematics, 1 yr high school chemistry...1 yr high school physics recommended; 3 lect, 1 lect discussion, 1 lab discussion plus one 4-hr lab per wk)
A consolidation of the basic principles of chemistry with those of qualitative and quantitative analysis; stoichiometry, development and use of structural concepts, energetics and geometry of molecule, bonding, and the behavior of the gaseous and liquid states.

1032. GENERAL PRINCIPLES OF CHEMISTRY. (5 cr, §1005; prereq 1031; 3 lect, 1 lect discussion, 1 lab discussion, plus one 4-hr lab per wk)
A continuation of the development of the basic principles of chemistry utilizing quantitative techniques; the solid state, theory of solutions, equilibrium, gas and condensed phases, behavior and nature of the solution process, acids, and bases.

1034. SYNTHESIS I. (5 cr; prereq 1032; 4 lect, 1 lab discussion, plus one 4-hr lab per wk)
Structure, synthesis, and reactions of organic compounds. The relationship of organic chemistry to problems of health and environment. Laboratory work to illustrate principles.

1301. CARBON COMPOUNDS. (4 cr; for students in engineering, except chemical and mining; prereq 1005, or 1032; 1301 cannot be substituted for 3301 or 3302; 4 lect hrs per wk)
Carbon compounds; emphasis on compounds useful as engineering materials, and processes by which such compounds are made.

3034. SYNTHESIS II. (5 cr; prereq 1034; 4 lect, 1 lab discussion, plus one 4-hr lab per wk) (Continuation of Chem 1034) The relationship of organic chemistry to living systems. Laboratory work to illustrate.

3100. QUANTITATIVE ANALYSIS. (3 cr, 3101†; for nonchemistry majors; prereq 1005)
Modern quantitative methods of analysis. Lecture.

3101. QUANTITATIVE ANALYSIS. (2 cr; for nonchemistry majors; prereq 3100 or ¶3100; 8 lab hrs per wk)
Modern quantitative methods of analysis, including elementary physicochemical procedures. Laboratory.

3102. INTRODUCTION TO ANALYTICAL CHEMISTRY. (4 cr; for physics majors; prereq 1014; 3 lect and 4 lab hrs per wk)
Equilibria involved in analytical processes. Properties and formation of precipitates. Methods of separation. Introduction to electrochemical methods.

3201. RATES AND MECHANISMS. (5 cr; prereq 3034 or equiv; 3 lect, one 3-hr lab plus lab discussion ar per wk)
Fundamentals of rates and mechanisms of chemical processes. Potential energy surfaces. Absolute rate theory.

3301. ELEMENTARY ORGANIC CHEMISTRY. (5 cr; prereq 1005 or 1032 or equiv; 3 lect, 1 lab conf, 1 quiz, and 4 lab hrs per wk)
Important classes of organic compounds, both aliphatic and aromatic, together with some heterocyclic compounds. In laboratory, the preparation of typical substances.

3302. ELEMENTARY ORGANIC CHEMISTRY. (5 cr; prereq 3301; 3 lect, 1 lab conf, 1 quiz, and 4 lab hrs per wk)
See Chem 3301.

3303. ELEMENTARY ORGANIC CHEMISTRY. (4 cr; prereq 3302 or 3034; 4 lect per wk)
Basic principles of organic chemistry, with emphasis on a survey of organic reaction mechanisms, intended to coordinate the knowledge which has been acquired in the preceding 2 quarters of organic chemistry.

3304. ELEMENTARY ORGANIC CHEMISTRY LABORATORY. (4 cr; prereq 3303 or ¶3303 or ¶3201; 8 lab hrs and 1 lect and 1 conf hr per wk)
Reactions of typical functional groups and introduction to methods of organic qualitative analysis.

3499. SENIOR THESIS. (Cr ar; prereq ‡, 4th yr)
Written final senior thesis report.

3590. INTRODUCTION TO PRINCIPLES OF CHEMISTRY. (3 cr; prereq Math 1111 or equiv and 1 yr general chemistry and 1 yr college physics)
Especially for biological concentrators minoring in biochemistry.

3591, 3592, 3593. SPECIAL TOPICS IN PHYSICAL CHEMISTRY. (2 cr per qtr; primarily for 3rd- and 4th-yr chemistry majors; prereq 2 qtrs physical chemistry)
Topics in physical chemistry—areas of current research.

3752, 3753. ADVANCED INORGANIC CHEMISTRY LABORATORY. (2 cr per qtr; prereq 3751 or 5703, ‡)
Advanced laboratory work in physical and synthetic methods. Specific experiments will be determined by student-instructor consultation. Detailed instructions for a wide variety of experiments.

5120. PHYSICAL-CHEMICAL METHODS OF ANALYSIS. (4 cr; prereq elementary analytical chemistry and 5501; 3 lect, 1 dem per wk)
Lecture. Optical and electrochemical methods and methods of separation. *Final offering 1973-74.*

5121. PHYSICAL-CHEMICAL METHODS OF ANALYSIS. (4 cr; prereq 5120)
Laboratory course. Quantitative application of electrochemical, optical, and other physical techniques. *Final offering 1973-74.*

5122. ADVANCED ANALYTICAL CHEMISTRY. (4 cr; prereq 3100 and 3101 or 1032)
Equilibria in aqueous and nonaqueous systems.

5123. ELECTROCHEMICAL METHODS OF ANALYSIS. (4 cr; prereq 5120 or 8101)
Lecture. Potentiometric, coulometric, polarographic, and other electrical methods.

5124. ELECTROCHEMICAL METHODS OF ANALYSIS. (3 cr; prereq 5123)
Laboratory course.

5125. INTRODUCTION TO INSTRUMENTAL MEASUREMENTS. (5 cr; prereq 5505 or ‡; 3 lect and two 4-hr labs per wk)
Instrumental techniques for detection and measurements; analysis of signal flow in control systems; principles of frequency-domain and time-domain filtering, and introduction to information flow in nonlinear systems.

5126. MODERN ANALYTICAL CHEMISTRY. (5 cr; prereq 3034; 2 lect, two 3-hr labs and 1 lab discussion per wk)
Strategies and techniques for solving modern analytical problems. The use of modern instruments in analysis.

5127. ANALOG INSTRUMENTATION. (5 cr; prereq Phys 1291, Math 3211; 3 lect and two 4-hr labs per wk)
Basic principles of electronic design and circuitry, servo systems, operational amplifiers, feedback control, oscillators.

5128. DIGITAL INSTRUMENTATION. (5 cr; prereq Phys 1291, Math 3211; 3 lect and two 4-hr labs per wk)
Simple switching devices such as semiconductor diodes and transistors; high-speed integrated circuits; binary, decimal, and modulo-M counters.

5211. ADVANCED CHEMICAL KINETICS. (4 cr; prereq 3201 and 5505)
Study of the factors which govern the rates of chemical reactions in both gaseous and condensed phases. Deduction of reaction mechanisms from rate data and theoretical interpretation in terms of dynamical and statistical models. Coupled reactions.

5301. SPECTRAL METHODS FOR ORGANIC QUALITATIVE ANALYSIS. (4 cr, §8302; prereq 3303; 3 lect and 1 conf hr per wk)
Practical application of nuclear magnetic resonance and infrared spectral analysis to solution of organic problems.

5302. ORGANIC SYNTHESIS. (4 cr; prereq 3201 or 3303; 8 lab hrs and 2 conf hrs per wk)
Reactions of typical functional groups and introduction to modern laboratory methods of organic synthesis.

5305. INTERMEDIATE ORGANIC CHEMISTRY. (4 cr; prereq 3201 or 3303; 3 lect and 1 rec hrs per wk)
Introduction to various aspects of physical organic chemistry with application to typical chemical problems. Reactions of typical functional groups and introduction to modern laboratory methods of organic synthesis.

5309. THEORETICAL ORGANIC CHEMISTRY. (4 cr; prereq 5502 or Phys 3501 or ♯; 3 lect and 1 rec hrs per wk)
Application of quantum mechanics to organic reactions and photochemistry.

5310. CONSUMER CHEMISTRY. (4 cr; prereq 3034 or equiv or ♯; offered spring 1974)
Understanding the role of chemistry in relevant consumer concerns.

5342. CHEMISTRY OF NATURAL PRODUCTS. (3 cr; prereq 3303; offered 1974-75 and alt yrs)
Biosynthesis of secondary natural products with emphasis on alkaloids, terpenes, and acetogenins.

5344. HETEROCYCLIC COMPOUNDS. (3 cr; prereq 3303; offered 1973-74 and alt yrs)
Typical classes of heterocyclic compounds, their chemical and physical properties and uses, synthesis.

5365. ORGANIC QUALITATIVE ANALYSIS. (4 cr, §3304; prereq 3201 or 3303; 8 lab and 2 conf hrs per wk)
Reactions of typical functional groups and introduction to methods of organic structure determination.

5502. QUANTUM MECHANICS. (5 cr; prereq 1 yr college chemistry, Phys 1291 or ¶Phys 1291, or 1106 with ♯, Math 3211)
Introductory quantum mechanics course for chemists. Laboratory illustrates the quantum properties of nature.

5505. STATISTICAL THERMODYNAMICS. (4 cr; prereq 1 yr college chemistry, Phys 1291 or ¶Phys 1291, or 1106 with ♯, Math 3211)
Classical statistical mechanics as applied to lattice model treatments of liquids and solutions.

5510. ANALYSIS OF DATA. (1 cr; prereq 5501 or 5502 or 5521)
Statistical and numerical treatment of physicochemical measurements. *Final offering 1973-74.*

5511, 5512. LABORATORY. (1, 2, or 3 cr per qtr; prereq 5510)
Measurement and interpretation of physicochemical properties. *Final offering 1973-74.*

5520-5521. ELEMENTARY PHYSICAL CHEMISTRY. (3 cr per qtr; prereq 1 yr college chemistry, Phys 1291 or ¶Phys 1291 or 1106 or ♯, Math 3211)
Brief general survey. 5520: Chemical thermodynamics. 5521: Kinetics, statistical mechanics, molecular structure.

5522. BIOPHYSICAL CHEMISTRY: STRUCTURE. (4 cr, §BioC 5522; prereq 2 qtrs physical chemistry...BioC 5741, 5002 or equiv desirable)
Methods of structure determination of biological macromolecules. Molecular weight determination, hydrodynamics, scattering and diffraction, optical and magnetic resonance spectroscopy. Application to proteins, nucleic acids, polysaccharides, synthetic analogs, and membrane transport.

5523. BIOPHYSICAL CHEMISTRY: ENERGETICS. (3 cr, §BioC 5523; prereq 2 qtrs physical chemistry...BioC 5741, 5002 or equiv desirable)
Energetics of biochemical reactions. Titration, binding, and folding stabilization in macromolecules. Conformational changes and cooperatives behavior. Coupling and energy gradients in transport.

5524. BIOPHYSICAL CHEMISTRY: DYNAMICS. (4 cr, §BioC 5524; prereq 2 qtrs physical chemistry...BioC 5741, 5002 or equiv desirable)
Application of thermodynamics, statistical mechanics, and chemical kinetics to biological systems. Theoretical and experimental enzyme kinetics, solvent effect, structure-function relation.

5530. THERMODYNAMICS. (4 cr; prereq minimum of 2 qtrs physical chemistry)
Application to gases, chemical reactions, solutions, phase equilibria.

5531. FOUNDATIONS OF QUANTUM CHEMISTRY. (4 cr, §5502; prereq Phys 1291 or equiv plus Math 3211 or 3411 or equiv plus ‡)
Postulates of quantum mechanics. Introduction to wave functions, solutions of the Schroedinger equation, variation and perturbation theory, introduction to modern techniques for calculating bound state wave functions and electronic energies of molecules, other material which is necessary background for Chem 8305 and/or Chem 8705.

5571-5572. MOLECULAR SPECTROSCOPY. (4 cr per qtr; prereq 5502 or 5531 or equiv for 5571)
An examination of various types of molecular spectroscopy from the standpoint of how structure information is obtained from spectra.

5574. MOLECULAR STRUCTURE AND SCATTERING. (3 cr; prereq 5572)
Determination of geometrical structure of molecules by X-ray, electron and neutron scattering. The effect of internal molecular motions on the structural determination. Inelastic scattering and molecular energies.

5580. PHYSICAL CHEMISTRY OF POLYMERS. (3 cr; prereq 5503 or 5505 or ‡; offered spring 1973-74 and alt yrs)
Molecular weight distribution, statistical mechanics of polymer solutions, network polymers, viscosity, light scattering, viscoelastic behavior.

5610. POLYMERIC MATERIALS. (4 cr, §MatS 5610; prereq 5501 or 5505 or ‡; 3 lect and one 3-hr lab per wk)
Polymerization and structure of synthetic and bipolymers. Crystallinity, physical properties, and viscoelastic behavior. Application of polymers and their environmental degradation.

5701. INORGANIC CHEMISTRY I. (4 cr; prereq 5501, 5502; 3 lect and 1 conf hrs per wk)
Atomic structure, structure and bonding in covalent molecules and ionic crystals, thermochemistry of chemical bonding. Applications to chemistry of nontransition elements. *Final offering 1973-74.*

5703. ADVANCED INORGANIC CHEMISTRY. (5 cr; prereq 3201 and 5502; 3 lect, 1 discussion, and one 3-hr lab per wk)
Modern treatment of transition and nontransition metal chemistry. Structure, bonding, and stereochemistry of inorganic and organometallic compounds. Selected current topics.

5704. ECOLOGY OF WATER. (4 cr; prereq 5505 or equiv or ‡; offered winter 1973-74)
Interaction of water with the gases, elements, and compounds of the biosphere.

5705. SYMMETRY IN CHEMISTRY. (5 cr; prereq 5703)
Introduction to group theory: symmetry classification of inorganic and organic molecules; representations of symmetry point groups; and the symmetry of wave functions. Symmetry aspects of molecular orbital theory and symmetry control of organic and inorganic reactions.

5710. ADVANCED INORGANIC CHEMISTRY I: SURVEY OF THE TRANSITION METALS. (4 cr; prereq 1 yr each of organic and physical chemistry)
Reactions and properties of the transition metals, including the rare earths, and their compounds. A survey of coordination chemistry using elementary ideas of ligand field theory.

5711. ADVANCED INORGANIC CHEMISTRY II: SURVEY OF THE CHEMISTRY OF THE NONTRANSITION ELEMENTS. (4 cr; prereq 1 yr each of organic and physical chemistry)
Reactions and properties of the nontransitional elements, including the rare gases, and their compounds.

5791, 5792, 5793. SELECTED TOPICS IN INORGANIC CHEMISTRY. (2 cr per qtr; prereq 5702, △)
Topics of current interest in inorganic chemistry.

FOR GRADUATE STUDENTS ONLY

8100. GENERAL SURVEY OF ANALYTICAL CHEMISTRY

8101. PHYSICAL-CHEMICAL METHODS OF ANALYSIS (Lecture)

8102. PHYSICAL-CHEMICAL METHODS OF ANALYSIS (Laboratory)

8104. OPTICAL METHODS OF ANALYSIS

8190. SEMINAR: MODERN PROBLEMS IN CHEMISTRY INSTRUMENTATION AND ANALYSIS

8198. RESEARCH SEMINAR: CHEMICAL INSTRUMENTATION AND ANALYSIS

8211. FUNDAMENTALS OF CHEMICAL DYNAMICS

8212. CHEMICAL DYNAMICS IN SOLUTION

8213. CHEMICAL DYNAMICS IN THE GAS PHASE

8294. MECHANISMS OF INORGANIC AND ELECTRODE REACTIONS

8300. GENERAL SURVEY OF ORGANIC CHEMISTRY

8301. ADVANCED ORGANIC CHEMISTRY

8302. INTRODUCTION TO RESEARCH

8303. PHYSICAL ORGANIC CHEMISTRY

8304. ADVANCED ORGANIC CHEMISTRY

8305. THEORETICAL ORGANIC CHEMISTRY

8341. STEREOCHEMISTRY

8342. INTRODUCTION TO RESEARCH

8343. THEORETICAL ORGANIC CHEMISTRY

8344. THEORETICAL ORGANIC CHEMISTRY

8390. ORGANIC CHEMISTRY SEMINAR

8500. GENERAL SURVEY OF PHYSICAL CHEMISTRY

8510-8511. QUANTUM MECHANICS

8512. SCATTERING THEORY

8513. GROUP THEORETICAL METHODS IN CHEMISTRY

8514. MOLECULAR QUANTUM MECHANICS

8515. INTERACTION OF RADIATION WITH MATTER

8520-8521. STATISTICAL MECHANICS

8560. SEMINAR: PHYSICAL CHEMISTRY OF BIOLOGICAL SYSTEMS

8565. SEMINAR: PHYSICAL CHEMISTRY OF POLYMERS

8570. SEMINAR: MOLECULAR SPECTROSCOPY

8575. SEMINAR: MAGNETOCHEMISTRY

8580. SEMINAR: PHOTOCHEMISTRY

8585. SEMINAR: THEORETICAL CHEMISTRY

8589. SEPARATION THEORY

8590. SEMINAR: PHYSICAL CHEMISTRY

8601-8602-8603. MOLECULAR THEORY OF TRANSPORT PROCESSES

8700. GENERAL SURVEY OF INORGANIC CHEMISTRY

8703. ADVANCED INORGANIC CHEMISTRY I

8704. ADVANCED INORGANIC CHEMISTRY II

8705. ADVANCED INORGANIC CHEMISTRY III

8751-8752-8753. ADVANCED INORGANIC CHEMISTRY LABORATORY METHODS

8790. SEMINAR: MODERN PROBLEMS IN INORGANIC CHEMISTRY

8990. RESEARCH IN CHEMISTRY

8991, 8992, 8993. SPECIAL TOPICS IN CHEMISTRY

Civil Engineering (CE)

General Courses

1001. CIVIL ENGINEERING ORIENTATION. (1 cr)
Fundamentals of civil engineering practice presented by professional engineers and members of the faculty.

3010. DATA ANALYSIS AND OPTIMIZATION IN CIVIL ENGINEERING. (4 cr; prereq Math 3221, CICS 3101 or equiv; 3 lect and 2 lab hrs per wk)
Introduction to probability, random variables, sampling, statistical inference, regression and correlation, comparison of means, linear programming, and computer programming.

3050. ENGINEERING INTERN WORK ASSIGNMENT. (4 cr [may be taken for cr twice]; prereq regis in intern program)
Grades based on formal written report by the student covering his work during professional assignment.

5001. BUILDING AND CONSTRUCTION CONTRACTS AND SPECIFICATIONS. (4 cr)
Synopsis of the law of contracts, sales, agency, negotiable instruments, real property, personal property, partnerships, corporations, insurance contracts, and torts with applications to the performance of engineering and construction contracts.

5097, 5098, 5099. ADVANCED DESIGN, ANALYSIS, RESEARCH, OR TUTORIAL IN CIVIL ENGINEERING. (Cr ar [may be repeated for cr]; prereq approval of faculty adviser)
Planning, design, or analysis of complex civil engineering systems. Individual laboratory research problems, literature, studies, and reports supervised by staff. Studies may be conducted in any discipline within civil engineering including but not limited to hydraulics and hydrology, land development, materials, environmental engineering, soil mechanics, structures, and transportation.

Surveying and Land Use Planning

3100. SURVEYING. (4 cr; prereq Math 1211 or equiv; 3 lect and 3 lab hrs per wk)
The theory, analysis, and execution of control surveys to determine the horizontal and vertical position of points in mapping, engineering, projects, cadastral surveys, and for construction layout. Elements of map construction and use. Field problems in use of surveying instruments.

3101. PHOTOGRAMMETRY. (4 cr; prereq Math 1211 or equiv; 3 lect and 2 lab hrs per wk)
The theory and methods of making planimetric and topographic maps by photogrammetric method using aerial and terrestrial photography. Laboratory problems in use of stereoscopes and second-order plotters. Photo interpretation and measurement.

3102. SURVEY DESIGN AND ANALYSIS. (4 cr; prereq Math 1211 or equiv; 3 lect and 3 lab hrs per wk)
Study of land ownership, property rights, and descriptions; geometric design of engineering projects; fitting of design to topography including analysis and computations of earthwork and drainage; land development regulations.

5100. LAND SURVEYING. (4 cr; prereq 3100, 3102 or ‡)
Minnesota Public Land Survey. Federal and state laws governing resurveys, registered land surveys, and subdivision plats. Court decisions and legal principles involving boundary line determinations. Interpreting and writing deed descriptions.

5101. GEODETIC SURVEYING. (4 cr; prereq 3101, 3102 or ‡)
Precise survey control nets, astronomic azimuth and error analysis for geodetic surveys. Theory and field problems in electronic surveying, celestial observations, and least squares adjustments.

Transportation

3200. INTRODUCTION TO TRANSPORTATION ENGINEERING. (4 cr; prereq Phys 1271 or equiv)
The application of the physical laws of motion and energy as they relate to calculations of resistances to motion, power, and energy requirements, acceleration-deceleration limits and capacity of various modes of transportation. Introduction, engineering economics with particular emphasis on costs of transportation systems.

5200. GEOMETRIC DESIGN OF HIGHWAYS. (4 cr; prereq 3200, 3102, or ‡)
Forecast of traffic volume demand; impact of vehicle type on geometric design; vertical and horizontal alignment; intersection design; highway capacity.

5201. HIGHWAY TRAFFIC CHARACTERISTICS AND OPERATIONS. (4 cr; prereq 3200 or equiv)
Characteristics and measurements of volume, speed, density, and travel time; characteristics of vehicles and road users; parking characteristics and design of facilities; applications of signs, signals, and markings in traffic control.

5202. AIRPORT DESIGN. (4 cr; prereq 3200, 3300)
Nature of air transport. Airfield site selection and runway patterns. Geometric design of runways; capacity. Drainage and pavement design.

5210. INTRODUCTION TO TRANSPORTATION PLANNING. (4 cr; prereq ‡)
Outline of the transportation planning process as applied to urban areas; data requirements and travel characteristics; trip generation analysis; models of travel distribution; transit characteristics and usage; selection and evaluation of alternate transportation proposals; transportation and land use linkages.

Soil Mechanics and Geo-Engineering

3300. ELEMENTS OF SOIL MECHANICS. (4 cr; 3 lect and 3 lab hrs per wk)
Physical properties of soils; relationships with water; stress distribution. Classification, compaction, and strength tests. Geological features and engineering properties of rocks.

5304. DESIGN OF HIGHWAY AND AIRPORT PAVEMENTS. (4 cr; prereq 3300, 3700)
Theories of pavement design, flexible and rigid; equivalent wheel loads. Strength tests and frost action. Design procedures for flexible and rigid pavements.

5310. FOUNDATION ENGINEERING. (4 cr; prereq 3300)
Applications of soils engineering to design and construction of various foundation types. Shallow foundations, deep foundations, retaining structures.

5311. SHEAR STRENGTH OF SOILS. (4 cr; prereq 3300; 3 lect and 3 lab hrs per wk)
Methods for evaluating the strength of various soils to be used for engineering projects.

5312. SLOPE STABILITY. (4 cr; prereq 3300)
Analysis of safety of various slopes and embankments considering such aspects as seepage forces, shear strength, and slope geometry.

Water Resources and Hydraulic Engineering

3400. FLUID MECHANICS. (4 cr, §AEM 5200; prereq Math 3221; 3 lect and 3 lab hrs per wk)
Fluid statics and dynamics for liquid and gases. Kinematics of fluid flow, viscous effects, and introduction to incompressible and compressible duct flow.

5401. WATER RESOURCES ENGINEERING. (5 cr; prereq 3400 or AEM 5200 or ‡; 4 lect and 3 lab hrs per wk)
Introduction to hydrology including precipitation and flood analysis; hydraulic engineering, including conduit flow, pumps, open channel flow, culvert flow, flow measurement and waves; hydraulic structures; introduction to the systems approach.

5402. HYDRAULIC ANALYSIS. (4 cr; prereq 5401 or ‡; 3 lect and 3 lab hrs per wk)
Computer application in hydraulic engineering, open channel controls, spillways and stilling basins, bridge waterways, culvert analyses, selected problems in conduit flow, wave action on breakwaters, elementary water hammer and surge analysis.

5405. HYDROLOGY. (4 cr; prereq 5401 or ‡; 3 lect and 3 lab hrs per wk)
Hydrologic cycle, precipitation, evaporation infiltration, runoff analysis, flood routing, statistical procedures in hydrology, urban hydrology, introduction to mathematical models of medium and large watersheds.

5410. OPEN CHANNEL HYDRAULICS. (4 cr; prereq 5401 or ‡; 3 lect and 2 lab hrs per wk)
Mechanics of flow in open channels including gradually varied, spatially varied, and rapidly varied flow; unsteady flow (waves and surges) and flow in alluvial channels.

5420. INTRODUCTION TO WATER RESOURCES MANAGEMENT. (4 cr)
The present state of the water resources; water resources planning; activation of planning.

5435. INTERMEDIATE FLUID MECHANICS WITH APPLICATIONS. (4 cr; prereq 3400)
Basic laws and equations of fluid flows; exact and approximate solution; very viscous flow; flow through porous media, potential flows, interfacial flows; boundary layer flow; turbulence and transport phenomena.

Environmental Engineering

3500. INTRODUCTION TO ENVIRONMENTAL ENGINEERING. (4 cr; prereq 3400 or ¶3400 or ‡)
Needs of urbanized society and their impact on the environment; physical, chemical, and biological characterization of the environment; environmental quality standards; technology for pollution abatement.

5500. ANALYSIS AND DESIGN OF WATER SUPPLY SYSTEMS. (4 cr; prereq 3500 or ‡; 3 lect and 3 lab hrs per wk)
Planning and engineering design considerations in developing water supply systems for urban centers. Supply quality, storage, treatment, distribution, and cost analysis.

5501. ANALYSIS AND DESIGN OF WASTE WATER SYSTEMS. (4 cr; prereq 3500 or ‡; 3 lect and 3 lab hrs per wk)
Planning and engineering design considerations in developing waste disposal systems for urban centers. Characterization of the volumes and quality of the waste streams, treatment and ultimate disposal of domestic, industrial waste waters, and storm water runoff. Environmental effects, cost, and political aspects of ultimate disposal.

5505. MANAGEMENT OF THE AQUATIC ENVIRONMENT. (4 cr; prereq ‡)
Man's impact on the aquatic environment. Water quality objectives; mathematical models are used to assess the quantitive effects of pollution sources. Alternatives for pollution abatement considered in terms of the model. Interrelationships between solid waste disposal, air quality, and water quality.

5510. SOLID WASTE MANAGEMENT. (4 cr; prereq ‡)
Solid waste disposal for urban areas in terms of volume, composition, and chemical characteristics. Methods and equipment of collection and treatment. Various disposal methods in terms of their effects on the environment and the unit costs.

Structural Engineering

3600-3601. ELEMENTARY STRUCTURAL DESIGN FOR ARCHITECTS. (4 cr per qtr; prereq AEM 3093)
Elementary structural analysis and design of frame buildings in steel and timber. Reinforced concrete for buildings and foundations.

3605. INTRODUCTION TO STRUCTURAL ANALYSIS. (4 cr; prereq AEM 1015)
Principles of structure mechanics; forces and deformations in one-dimensional structural elements; elementary design considerations.

5600. LINEAR STRUCTURAL SYSTEMS. (4 cr; prereq 3605)
Analysis of elementary indeterminate structural systems; introduction to the stiffness and flexibility methods of analysis; torsion and biaxial bending; stability of framework; design considerations.

5601. ANALYSIS OF STRUCTURES I. (4 cr; prereq 5600)
Analysis of linear structural systems by matrix methods.

5602. STRUCTURAL ANALYSIS II. (4 cr; prereq 5600)
Analysis of plate and shell structures; use of the finite element technique.

5610. DESIGN OF METAL STRUCTURES. (4 cr; prereq 5600)
Elastic and plastic philosophies of design and related properties of structural metals. Design of tension members, columns, beams, trusses, buildings, and bridges. Connections, plastic design.

5611. DESIGN OF REINFORCED CONCRETE STRUCTURES. (4 cr; prereq 5600)
Working stress and ultimate load philosophies of design and their relation to physical properties of steel and concrete. Design of continuous beams, columns, slabs, footing. Relation of code provisions to field and laboratory measurements.

Construction Materials

3700. INTRODUCTION TO CONSTRUCTION MATERIALS. (4 cr; prereq AEM 1015; 3 lect and 3 lab hrs per wk)
Basic concepts of the behavior mechanisms of materials and the characterization of specific materials such as concretes, metals, woods, and other materials.

5701. CEMENTED MATERIALS: PROPERTIES, EVALUATION, AND MIXTURE DESIGN. (4 cr; prereq 3700; 3 lect and 3 lab hrs per wk)
Characteristics and performance evaluation concepts of construction materials; properties and design of cemented mixtures such as concrete, bituminous mixtures, stabilized soils and rocks.

5702. MANUFACTURE AND QUALITY CONTROL OF CONSTRUCTION MATERIALS. (4 cr; prereq 3700; 3 lect and 3 lab hrs per wk)
Methods of manufacture, especially of cemented materials such as concrete, stabilized soils and rock; expected variations and quality control concepts; optimization techniques developed to establish procedures and best material to use for a given situation.

FOR GRADUATE STUDENTS ONLY

8097-8098-8099. CIVIL ENGINEERING RESEARCH

8200. SEMINAR: THEORY OF TRAFFIC FLOW

8201. SEMINAR: URBAN TRAFFIC OPERATIONS

8202. SEMINAR: FREEWAY TRAFFIC OPERATIONS

8210. SEMINAR: ADVANCED TRANSPORTATION PLANNING

8300-8301. ADVANCED SOIL MECHANICS LABORATORY

8302. ADVANCED HIGHWAY LABORATORY

8303. SPECIAL PROBLEMS IN CONCRETE MATERIALS

8310. FOUNDATION AND HARBOR ENGINEERING

8400. HYDRAULIC TRANSIENTS

8410. FLUID TURBULENCE

8412. MECHANICS OF SIMILITUDE AND DIMENSIONAL ANALYSIS

8413. MECHANICS OF SEDIMENT TRANSPORT

8415. WATER POWER

8416. HYDRAULIC MEASUREMENTS

8417. HYDRAULIC PUMPS AND TURBINES

8419. WATER RESOURCES SYSTEMS SIMULATION

8420. WATER RESOURCES SYSTEMS

8421. INCOMPRESSIBLE POTENTIAL FLOW

8422. INCOMPRESSIBLE BOUNDARY LAYER FLOW

8425. GROUNDWATER HYDRAULICS

8430. LAKE, RESERVOIR, AND OCEAN HYDRODYNAMICS

8431-8432-8433. HYDRODYNAMICS OF THE BOUNDARY LAYER

8435-8436-8437. SPECIAL TOPICS IN HYDRODYNAMIC THEORY

8497-8498-8499. ADVANCED HYDRAULIC LABORATORY

8500. WATER PLANT DESIGN

8501. ADVANCED SANITARY ENGINEERING (Water)

8505. WASTE WATER PLANT DESIGN

8506. ADVANCED SANITARY ENGINEERING (Waste Water and Industrial Wastes)

8507. INDUSTRIAL WASTE DISPOSAL

8510. SANITARY ENGINEERING UNIT OPERATIONS

8515-8516. CHEMICAL AND BIOLOGICAL ASPECTS OF SANITARY ENGINEERING I, II

8550. ANALYSIS AND MODELING OF THE AQUATIC ENVIRONMENT

8551. SEMINAR: MODELS OF AQUATIC ENVIRONMENT

8605-8606. APPROXIMATE METHODS OF STRUCTURAL ANALYSIS I, II

8608. ADVANCED THEORY OF STRUCTURES

8609. PRINCIPLES OF STRUCTURAL STABILITY

8610. SHELL STRUCTURES

8612. STRUCTURAL DESIGN BY ULTIMATE LOAD THEORY

8620-8621. STRUCTURAL DYNAMICS I, II

8697-8698-8699. SEMINAR: STRUCTURES

Computer, Information, and Control Sciences (CICS)

1100. INTRODUCTION TO FORTRAN PROGRAMMING I. (2 cr; prereq Math 1211 or 1311 or 1611 or ¶Math 1211 or ¶1311 or ¶1611 or ‡; informal lab)
Introduction to computer programming using FORTRAN; elementary-intermediate level applications. A choice of problems is provided to allow for students from different academic disciplines. See CICS 3101 for comparison.

1101. INTRODUCTION TO FORTRAN PROGRAMMING II. (2 cr [not open for cr to CICS majors]; prereq 1100 and Math 1211 or 1311 or 1611 or ‡; informal lab)
(Continuation of 1100) Extended applications including some numerical methods.

1105. FUNDAMENTALS OF ALGORITHMS AND LANGUAGES I. (4 cr; prereq 1100 or equiv programming knowledge or ‡...Math 1231 or 1331 or Math 1621 or ‡; informal lab)
(First course in required basic sequence for CICS majors) Algorithms, their properties and representation. Elementary concepts in linguistics: syntax, semantics, ambiguities. FORTRAN as a language; applications of FORTRAN to different algorithms, e.g., iteration and recursion, sequential and binary searching, numerical methods.

1106. FUNDAMENTALS OF ALGORITHMS AND LANGUAGES II. (4 cr; prereq 1105 or ‡; informal lab)
Algorithms for nonnumerical data types. Tree structures, lists, strings, simulations, sorting, hashing, elementary graph theory, game playing. Languages for string processing and symbol manipulation; SNOBOL. Language translation. Students will write FORTRAN and SNOBOL programs in several of the above areas.

3001. PERSPECTIVES ON COMPUTERS AND SOCIETY. (4 cr; prereq soph or ‡; informal lab)
The impact of computers on society. Partnership or confrontation. History of development. Potential for use. Computer utility. Privacy in a computer society. The future of computers. The ultimate machine. Computers in business, industry, art, music, the home.

3101. A FORTRAN INTRODUCTION TO COMPUTER PROGRAMMING. (4 cr; intended for non-CICS majors; prereq Math 1231 or 1331 or 1621 or #)
FORTRAN computer language with extensions; applications; programming techniques. Brings students to advanced-level competence in FORTRAN programming. Integral nonscheduled laboratory.

3107. INTRODUCTION TO ASSEMBLY LANGUAGE PROGRAMMING. (4 cr, §5101; intended for CICS majors...nonmajors should take 5101; prereq 1101 or 1105 or 3101 or #; informal lab)
Number bases and representation. Analysis of a simple computer: machine language instructions, addressing, indexing. Assembly language coding: floating point arithmetic, looping, testing, character manipulation, logical operations; subroutine linkage and transfer. Students will write assembly language programs.

5001. THEORY AND APPLICATION OF LINEAR PROGRAMMING ALGORITHMS. (4 cr; prereq 1101 or 1105 or 3101, Math 3211 or 3142, or #; informal lab)
Convex polyhedral sets; extreme points; linear systems; primal and revised simplex algorithms; duality theory and Kuhn-Tucker conditions; postoptimality analysis; obtaining initial feasible solutions; storage and retrieval problems; use of commercial linear programming codes.

5002. COMPUTATIONAL METHODS FOR NONLINEAR PROGRAMMING. (4 cr; prereq 5001 or #; informal lab)
Convex functions and domains; nonlinear optimality conditions and duality; unconstrained minimization methods; convergence rates; minimization methods for linear and nonlinear constraints; penality functions; acceleration of convergence; nonconvex problems.

5101. STRUCTURE AND PROGRAMMING OF SOFTWARE SYSTEMS I. (4 cr, §3107; intended for non-CICS majors...majors should take 3107; prereq 1101 or 1105 or 3101 or #; informal lab)
Introduction to assembly language programming. Topics covered are essentially the same as those listed for 3107; however, the emphasis and projects will be geared to nonmajors.

5102. STRUCTURE AND PROGRAMMING OF SOFTWARE SYSTEMS II. (4 cr; prereq 3107 or 5101 or #; informal lab)
Subroutine coding conventions; argument transfer; interrupts and traps; macros; I/O equipment and operations; buffers; conditional assembly and program segmentation. Students will write assembly language programs for an existing, modern computer.

5103. INTRODUCTION TO ASSEMBLERS. (4 cr; prereq 5102 or #; informal lab)
Relocatability and base addressing. Creating an assembler; source code scanning, symbol table management, stacking, template macro processing, etc. Microprogramming. Students will design and run an assembler.

5104. SYSTEM SIMULATION: LANGUAGES AND TECHNIQUES. (4 cr; prereq 3107 or 5101, Stat 3091 or 5121 or #; informal lab)
Simulation methodology including random number generation, queuing, service times, discrete random variables, design of experiments. Simulation languages flow and event oriented: GPSS, SIMULA, SIMSCRIPT. Model building. Applications to job shops, business, operations research, and operating systems.

5105. THEORY OR MACHINE ARITHMETIC. (4 cr; prereq 3107 or 5101 or #; informal lab)
Residue class arithmetic. Congruences and complement arithmetic. Integral additive and subtractive accumulators. Multiplication and division by shifting and accumulation. Applications to absolute value and sign arithmetic, scaling and floating point operation.

5106. STRUCTURE OF HIGHER LEVEL LANGUAGES. (4 cr; prereq 5102 or #)
Formal definition of programming languages. Syntax. Semantics. The Algol Report. Introduction to Algol. Applications. Extensions of concepts to other languages. List structures. List languages. List processing. Basics of compilers and compiler implementation.

5107. COMPUTER GRAPHICS. (4 cr; prereq 3107 or 5101 or #)
Arrangement of data base and display files. Representation of data types of display equipment available, calligraphic and raster. Character generators. Display processors. Clipping, windowing, and the hidden surface problem. Applications.

5108. MATRIX DESCRIPTION AND SYNTHESIS OF LOGICAL ALGORITHMS FOR MICROPROGRAMMING. (4 cr; prereq 3107 or 5101, 5201, Math 3211, or ‡; informal lab)
A special matrix calculus is developed and applied to the description and synthesis of of combinational, iterative, and sequential networks. Applications to state reduction, minimization of logical algorithms, and structural implementation of microprograms.

5121. INTRODUCTION TO DATA STRUCTURES. (4 cr; prereq 5102 or ‡)
Basic concepts of data and its representation. Linear lists and strings. Array structures and allocation. Symbol tables and searching techniques; hash coding techniques. Tree structures. Storage systems and structures. Storage allocation. Multilinked structures. Sorting.

5122. ADVANCED DATA STRUCTURES. (4 cr; prereq 5121 or ‡; informal lab)
Data structure formalisms. Storage structures and organization. Data structures in programming languages. List processing languages. Data definition languages. Data base management systems and design. Problems in information system design. Applications to large data base problems.

5199. PROBLEMS IN LANGUAGES AND SYSTEMS. (1-4 cr per qtr [may be repeated for cr]; prereq ‡)
Special courses or individual study arranged with faculty member.

5200. INTRODUCTION TO ANALOG AND HYBRID COMPUTATION. (4 cr; prereq 1101 with ‡, and Math 3221 or 3061, or ‡; 3 lect and 1 lab hrs per wk)
Organization of and programming for analog and hybrid computers. Interface equipment including analog-to-digital and digital-to-analog conversion. Simulation languages. Case studies and problem solutions.

5201-5202. COMPUTER ENGINEERING. (4 cr per qtr; prereq 5102 or ‡; 3 lect and 1 lab hrs per wk)
(Same as EE 5350-5351) Boolean analysis, algebra, and operators in relay circuits. Analysis of Boolean networks. Limitations of practical circuits. Fan-in, fan-out relays. Algebraic synthesis. Multilevel factorization. The Cray borrow pyramid. Synchronous sequential circuits, Mealy model, flip-flop and clocking practices. System block diagrams. Register types and transfer methods. Clock generation and control. Polyphase clock generation. Sequences, sequence functions, ring counters.

5299. PROBLEMS IN MACHINE DESIGN. (1-4 cr per qtr [may be repeated for cr]; prereq ‡)
Special courses or individual study arranged with faculty member.

5301. NUMERICAL ANALYSIS. (4 cr, §Math 5472; prereq Math 3221, or Math 3142 and 3211, or ‡...a knowledge of FORTRAN is assumed; informal lab)
General concept of iteration formulas. Solution of equations. Newton's method. Linear systems. Finite differences. Interpolation. Numerical differentiation and integration. Introduction to initial value problems.

5302. NUMERICAL ANALYSIS. (4 cr, §Math 5473; prereq 5301 or ‡; informal lab)
General theory of linear approximations. Norms. Error estimates. Convergence rates. Least squares. Orthogonal polynomials. Chebychev interpolation theory. Gaussian quadrature. Further solutions of equations. Multipoint iteration formulas. Starting values. Iterative schemes for linear algebra. Conditioning. Jacobi's method. Differential equations. Initial value problems. Systems of equations. Runge-Kutta. Stability.

5304. COMPUTATIONAL ASPECTS OF MATRIX THEORY. (4 cr; prereq 5302 or ‡; informal lab)
Computational pitfalls. Conditioning. Iterative methods. Relaxation methods. Various reduction and elimination schemes. Hessenberg matrices. Methods of Lancos, Givens, Householder. Eigenvalue problems. Bounds for eigenvalues.

5305. NUMERICAL SOLUTIONS OF INITIAL AND BOUNDARY VALUE PROBLEMS. (4 cr; prereq 5302 or ‡; informal lab)
Linear two-point boundary value problems. The eigenvalue problem. Tau and Galerkin methods. Nonlinear two-point problems. Shooting method. Newton-Kantorovich method. Elements of numerical solutions of problems in partial differential equations. Laplace, heat, and wave equations.

5399. PROBLEMS IN NUMERICAL ANALYSIS. (1-4 cr per qtr [may be repeated for cr]; prereq ‡)
Special courses or individual study arranged with faculty member.

5400. INTRODUCTION TO AUTOMATA THEORY. (4 cr; prereq 1106 or ‡; informal lab)
Turing machines, computable functions, insolvability of the halting problem. Finite state models: equivalence, minimization, synthesis of finite state systems, state assignment, decomposition. Survey of other automata.

5401. INTRODUCTION TO FORMAL LANGUAGES. (4 cr; prereq 5400; informal lab)
Formal grammars and languages and their related automata. Language hierarchy. Context-free languages and grammars. Pushdown automata. Normal form theorems. Operations on languages. Decidability and undecidability results. Parsing algorithms. Applications to programming.

5499. PROBLEMS IN COMPUTATIONAL THEORY OR LOGIC. (1-4 cr per qtr [may be repeated for cr]; prereq ‡)
Special courses or individual study arranged with faculty member.

5501. ARTIFICIAL INTELLIGENCE AND HEURISTIC PROGRAMMING. (4 cr; prereq 1106 or ‡; informal lab)
Concept of a "mechanized" intelligence. The IQ of current systems. Game playing, particularly heuristic search techniques. Introduction to neural networks and their mechanical analogs. Methodologies in pattern recognition and applications. The frame problem in AI and implications for robotics. Natural language processing and deductive question answering.

5502. INTRODUCTION TO OPERATING SYSTEMS. (4 cr; prereq 5103 or ‡; informal lab)
Definition and historical development of operating systems. Classification of systems as batch-processing, interactive, and real-time systems. Abstractions and implementations of properties common to most systems. Concurrency and related control problems. Resource allocation. Storage allocation. Program modularity. Sharing. Multiplexing. Protection. Performance optimization.

5503. INTRODUCTION TO COMPILER CONSTRUCTION. (4 cr; prereq 5103 or ‡; informal lab)
Definition of a language; phrase structure languages; context-free languages and grammars; rigorous definition of typical small language in BNF. An actual compiler for programs written in this language is produced and executed: scan and classification of statements; symbol table construction and management; generation of intermediate text and assembly code.

5504. FORMAL METHODS IN COMPILER CONSTRUCTION. (4 cr; prereq 5503 or ‡; informal lab)
Syntax-directed approach to the "front-end" of a complier: review of finite state automata used by the lexical scanner; generative BNF grammars and their use in top-down parsing; boot-strapping techniques; precedence schemes and languages, production of a table-driven, efficient bottom-up parser.

5505. OPTIMIZATION IN COMPILERS. (4 cr; prereq 5503 or ‡; informal lab)
Automatic collection of global information encompassing the structure of the program; usage information for the variables; representation in terms of a program graph. Specific optimizations: elimination of common subexpressions; backward movement of code; strength reductions. Minimization of loads and stores. Optimal global assignment of registers.

5511. ADVANCED TOPICS IN ARTIFICIAL INTELLIGENCE. (4 cr; prereq 5501 and 5400, or ‡)
"Systems" employing AI techniques; examples including Shakey (the SRI robot), the hand-eye project at Edinburgh, the MIT robot project, etc. Methods of integrating eyes, hands, ears, etc., into a functioning unit. Natural language facilities including representational schemes, parsing algorithms, and semantic memories. Students will design and implement phases of a large ssytem.

5599, 5699, 5799. PROBLEMS: NONNUMERIC COMPUTATIONS, CONTROL SCIENCE, INFORMATION SCIENCE. (1, 2, 3, or 4 cr per qtr [course may be taken for more than 1 qtr]; prereq ‡)
Special courses or individual study arranged with faculty member.

FOR GRADUATE STUDENTS ONLY

8101-8102-8103. COMPUTER OPERATING SYSTEMS: MODELING AND ANALYSIS
8201-8202-8203. MATHEMATICS OF COMPUTERS AND CONTROL DEVICES

8301-8302. COMPUTATION OF SPECIAL FUNCTIONS AND FORMULAS

8303-8304. COMPUTATIONAL METHODS FOR INITIAL AND BOUNDARY VALUE PROBLEMS.

8199. SEMINAR: LANGUAGES AND SYSTEMS

8299. SEMINAR: MACHINE DESIGN

8399. SEMINAR: NUMERICAL ANALYSIS

8499. SEMINAR: COMPUTATIONAL THEORY AND LOGIC

8501. PATTERN RECOGNITION

8599. SEMINAR: NONNUMERIC COMPUTATION

8699. SEMINAR: CONTROL SCIENCE

8799. SEMINAR: INFORMATION SCIENCE

Electrical Engineering (EE)

1000. INTRODUCTION TO ELECTRICAL ENGINEERING. (1 cr; P-N only; prereq EE lower Div or △)
An introduction to electrical engineering presented by practicing engineers and members of the faculty.

1510. ELEMENTS OF ELECTRICAL ENGINEERING. (5 cr, §1500; prereq Phys 1291, Math 3221 or 3066; 5 lect-rec-dem hrs, 3 lab hrs per wk)
Physical principles underlying the modeling of circuit elements. Characterization of two- and three-terminal resistive elements. Kirchhoff's laws. Analysis of simple resistive circuits. Linearity in circuits. Characterization of storage elements. First-order circuits.

3000. CIRCUITS. (4 cr, §1500, §1700; not for EE majors; prereq Phys 1230 or 1291, Math 1250 or Math 3221 or ¶Math 1250 or ¶Math 3221; 3 lect and 2 rec or lab hrs per wk)
Analysis of linear passive circuits; natural and forced response. Steady-state ac analysis; resonance.

3001. ELECTRONICS. (4 cr; not for EE majors; prereq 1501 or 3000; 3 lect and 2 rec or lab hrs per wk)
Network theorems; two-ports, active device models; vacuum diodes, semiconductors, amplifiers, nonlinear devices; logic circuits.

3010-3011-3012. CIRCUITS, SIGNALS, AND SYSTEMS I, II, III. (4 cr per qtr, §1501-5000-5001; prereq 1510; 3 lect, 2 rec-dem hrs per wk)
3010: Modeling of lumped-parameter networks. Second-order circuits. Sinusoidal steady-state analysis. Two-port networks. 3011: Fourier methods of analysis. Laplace transforms and applications. Frequency and time-domain responses. 3012: Continuous, discrete-time systems. Feedback: stability, applications.

3050-3051. ELECTRONICS. (4 cr per qtr; prereq 3010-3011 or ¶; 3 lect, 2 rec-dem hrs per wk)
3050: Diode circuits and applications. Semiconductor properties. P-N junctions. Junction diodes; JFET characteristics; MOSFET characteristics. FET amplifiers; biasing. 3051: BJT characteristics. Biasing of BJT's. Low-frequency amplifiers: BJT's and FET's. Vacuum tubes. High-frequency amplifiers. Miller approximation, BJT's and FET's.

3050H-3051H. HONORS COURSE: ELECTRONICS I-II. (4 cr per qtr; prereq △)

3100-3101. ELECTROMAGNETIC FIELDS I, II. (4 cr per qtr; prereq Phys 1291, Math 3231 or ¶ with ♯; 3 lect hrs, 2 rec-dem hrs per wk)
Electrostatic, magnetostatic, and electromagnetic field theory based on fundamental experimental laws, including properties of dielectric and magnetic materials.

3100H-3101H. HONORS COURSE: ELECTROMAGNETIC FIELDS. (4 cr per qtr; prereq △)

3400-3401-3402. JUNIOR ELECTRICAL ENGINEERING LABORATORY. (3-3-2 cr per qtr; prereq 3050-3051-5050 or ¶)
The laboratory will include experiments in circuits, electronics, and electromagnetic fields.

3450H-3451H-3452H. ELECTRICAL ENGINEERING HONORS COURSE. (4-4-3 cr, §3400-3401-3402; prereq △)
Special studies for third-year students in EE honors program.

3460-3461-3462. SPECIAL INVESTIGATIONS. (Cr ar; prereq approval of faculty sponsor)
Undergraduate studies of approved topics, theoretical or experimental in nature.

3470-3471. SUMMER ENGINEERING EMPLOYMENT. (1-3 cr per qtr; prereq completion of 2nd- or 3rd-yr work, declaration of intention before end of spring qtr, regis in fall qtr)
Summer work of not less than 360 hours per summer in an engineering field. Requires a technical report.

3475. INDUSTRIAL ASSIGNMENT. (2 cr [may be taken for cr more than once]; prereq regis in intern program)
Industrial work assignment in engineering intern program. Grade based on student's formal written report covering his quarter's work assignment.

3950H-3951H-3952H. HONORS PROJECT. (3 cr per qtr; prereq △)
Design project for fourth-year students in EE honors program.

5000H-5001H. HONORS COURSE: LINEAR SYSTEM ANALYSIS. (4 cr per qtr; prereq △)

5002. METHODS OF NETWORK AND SYSTEM ANALYSIS. (4 cr; prereq 3012; 3 lect, 2 rec-dem-comp hrs per wk)
Topological and matrix methods. State-space methods. Discrete-time systems. Computer methods.

5010-5011. NETWORK SYNTHESIS. (4 cr per qtr; prereq 5001 or ♯; 3 lect and 2 lab hrs per wk)
Description of linear networks in the time and frequency domains. Properties of two- and three-element-kind networks. Approximation and realization problems in network synthesis. Design of RC, RL, LC, and RLC networks to realize driving-point and transfer functions and their applications.

5050. NONLINEAR ELECTRONIC CIRCUITS. (4 cr; prereq 3051, 3012 or ¶; 3 lect, 2 rec-dem hrs per wk)
Linear wave-shaping circuits. Piece-wise linear circuit analysis. Switching models of diodes and transistors. Transistor logic circuits. Bistable multivibrators. Astable multivibrators. Nearly sinusoidal oscillators.

5050H. HONORS COURSE: NONLINEAR ELECTRONIC CIRCUITS. (4 cr; prereq △)

5055. LINEAR ELECTRONIC CIRCUITS. (4 cr; prereq 3051, 5001 or ¶5001)
Electronic functions, device limitations, and biasing stability; frequency effects in single-stage, cascaded, and tuned amplifiers; power amplifiers. Introduction to design considerations.

5056. ELECTRONIC CIRCUITS LABORATORY. (1 cr; prereq 3402, ¶5055; 2 lab hrs per wk)

5060-5061. APPLIED ELECTRONICS I-II. (4 cr per qtr; prereq 5050, 5055; 3 lect and 2 lab hrs per wk)
Multistage amplifiers; broad-band, feedback, tuned transistor amplifiers; noise in amplifiers. Charge-control analysis of nonregenerative and regenerative switching circuits. Tuned power amplifiers and oscillators. Parametric amplifiers. Analysis and design including laboratory investigation of design.

5100. ELECTROMAGNETIC FIELDS III. (4 cr; prereq 3101; 3 lect hrs, 2 rec-dem hrs per wk)
Plane-wave propagation, transmission lines, antennas, and other topics.

5101. ELECTROMAGNETIC FIELDS LABORATORY. (1 cr; prereq 3401, 5100 or ¶)

5110-5111. APPLICATIONS OF ELECTROMAGNETIC THEORY. (4 cr per qtr; prereq 5100 or equiv; 3 lect and 2 lab hrs per wk)
Maxwell's equations. Poynting vector, propagation and reflection of plane waves. Transmission lines, wave guides, and resonant cavities. Radiation, interference, and diffraction. Other selected topics.

5150. ELECTRICAL ENGINEERING MATERIALS. (4 cr; prereq 3101, Phys 3500)
Electric, magnetic, and dielectric properties of materials as related to devices used in electrical engineering.

5160-5161. PHYSICAL ELECTRONICS. (4 cr per qtr; prereq 3050 or ‡; 3 lect and 2 lab hrs per wk)
Physical principles underlying devices used in electrical engineering; elementary quantum and statistical mechanics, semiconductor properties, electron emission from surfaces, special topics of current interest.

5200-5201. COMMUNICATIONS. (4 cr per qtr; prereq 5001, Stat 3092; 3 lect and 2 lab hrs per wk)
Theoretical and laboratory study of selected topics in electric communications. Spectral analysis; modulation theory and the effect of noise in modulation systems; multiplex systems; optimum filtering.

5250-5251. CONTROL SYSTEMS. (4 cr per qtr; prereq 5001, Math 3061, or ‡; 3 lect and 2 lab hrs per wk)
Analysis and applications of typical linear control elements; analysis and design of linear control systems in the frequency and time domains, using such techniques as Bode, Nyquist, and root-locus methods; analytic and graphical treatment of system stability.

5300. ELECTROMECHANICS. (4 cr; prereq 3101, 5001 or ¶5001)
Energy considerations in electromechanical devices; linear and nonlinear analysis of electromechanical energy converters; characteristics of specific rotary converter types obtainable from a generalized rotating machine.

5301. ELECTROMECHANICS LABORATORY. (1 cr; prereq 3402, ¶5300; 2 lab hrs per wk)

5310-5311. ELECTRIC POWER SYSTEMS. (4 cr per qtr; prereq 5001, 5300; 3 lect and 2 lab hrs per wk)
Modern electric power-system technology; response of rotating machines; complete electric power system: generation, transmission, distribution, and utilization. Balanced and unbalanced polyphase systems. Stability analysis of power systems. Digital computer applications to power-system problems.

5320-5321. APPLIED ELECTROMECHANICS. (4 cr per qtr; prereq 5001, 5300, or ‡; 3 lect and 2 lab hrs per wk)
Theory and application of translational and rotational electromechanical converters; transducers, sensors, and machines. Formulation of dynamic equations and methods of solution. Properties of materials, consideration of limitations they impose on device performance.

5350-5351. PRINCIPLES OF COMPUTER ENGINEERING. (4 cr per qtr, §5851-5852; prereq 3001 or 5050 or ‡; 3 lect and 2 lab hrs per wk)
Boolean algebra and combinatorial logic. Analysis and synthesis of sequential circuits. Design of digital systems and digital computers.

5450. SPECIAL INVESTIGATIONS. (Cr ar [may be repeated for cr]; prereq △)
Studies of approved topics, theoretical or experimental in nature.

FOR GRADUATE STUDENTS AND QUALIFIED SENIORS

5500. LINEAR NETWORK THEORY I. (3 cr; prereq 5001 or equiv)
Properties and synthesis of the driving-point and transfer functions of two- and three-element-kind networks. Theory of positive real functions.

5501-5502. LINEAR NETWORK THEORY II-III. (3 cr per qtr; prereq 5500 or equiv)
Relationship between parts of network functions. Approximation theory. Design of filters and pulse networks. Properties of reciprocal and nonreciprocal N-port networks. Synthesis of one-port and two-port networks using gyrators.

5503-5504. LINEAR ACTIVE NETWORKS. (3 cr per qtr; prereq 5500 or equiv, ¶5501-5502)
Network models of active devices. Analysis and synthesis of single-stage and cascaded amplifiers. Theory of feedback amplifiers and stability. Design of single-loop and multistage feedback amplifiers. Bandpass amplifiers.

5550-5551-5552. SWITCHING AND DIGITAL CIRCUITS. (3 cr per qtr; prereq 5050, 5055 or ‡)
Transient response of junction diodes, bipolar, and field-effect transistors; large-signal models of semiconductor devices; bistable, monostable, and astable semiconductor circuits in discrete and microelectronic forms; phase-plane analysis of large-signal oscillators; digital logic circuits, comparison of discrete and integrated circuits; calculation of circuit response by approximate methods and by digital computer; verification of circuit solutions by laboratory examples and problems.

5560. BIOMEDICAL INSTRUMENTATION. (4 cr; prereq grad standing or ‡)
Biological signal sources. Electrodes, microelectrodes, other transducers. Characteristics of amplifiers for biomedical applications. Noise in biological signals. Filtering, recording, and display. Protection of patients from electrical hazards. Experiments in neural and muscle stimulation, EKG and EMG recording, neuron simulation, filtering, and low-noise amplifiers.

5600-5601-5602. ELECTROMAGNETIC THEORY. (3 cr per qtr; prereq 5100, 5101 or equiv, grad standing or ‡)
Fields and waves with attention to mathematical formulation. Maxwell's equations and boundary value problems. Plane waves, transmission lines, wave guides, and resonators. Microwave networks. Inhomogeneous, anisotropic, and ionized media. Diffraction theory and optical resonators. Parametric systems.

5650. DYNAMICAL METHODS IN ELECTRICAL ENGINEERING. (3 cr; prereq grad standing or ‡)
Lagrangian and Hamiltonian formulations of dynamics, with applications to electromagnetic systems. Lagrange's equations; dissipative forces, normal coordinates and small oscillations; Hamilton's equations; variational principles for discrete and continuous systems.

5651. THERMODYNAMIC METHODS IN ELECTRICAL ENGINEERING. (3 cr; prereq grad standing or ‡)
Basic thermodynamic concepts and laws, with special application to electromagnetic systems. Energy, entropy, and thermodynamic potentials; application to electrically and magnetically polarizable materials, rigid or elastic, piezoelectricity, magnetostriction, thermoelectricity, reciprocal relations in reversible and irreversible processes.

5652. STATISTICAL-MECHANICAL METHODS IN ELECTRICAL ENGINEERING. (3 cr; prereq 5650, 5651 or ‡)
Classical and quantum-statistical mechanics, with application to materials and problems of electrical engineering. Statistical ensembles, phase space, Liouville's theorem, the canonical ensemble, the partition function. Classical and quantum statistics. Relation between statistical mechanics and thermodynamics. Classical and quantum calculations of susceptibilities.

5653. INTRODUCTORY QUANTUM MECHANICS FOR ENGINEERS. (3 cr; prereq grad standing or ‡)
Principles of quantum mechanics for students with engineering background; intended as preparation for solid state materials or quantum electronics. Wave equation, operator formalism, angular momentum, perturbation theory.

5660-5661-5662. SEMICONDUCTOR PROPERTIES AND DEVICES. (3 cr per qtr; prereq grad standing or ‡)
Principles and properties of semiconductor devices. Selected topics in quantum and statistical mechanics, crystal structures, semiconductor properties; transistor action and other device phenomena; influence of surfaces. Treatment of actual devices. Large-scale integrated-circuit design.

5700-5701. INFORMATION THEORY AND CODING. (3 cr per qtr; prereq Stat 3092 or ‡)
5700: Binary arithmetic, logic; discrete information sources and channels, coding, the binary channel and Shannon's second theorem. 5701: The continuous channel; error detection and correction codes, random coding; channels with feedback, the two-way channel.

5702. STOCHASTIC PROCESSES AND OPTIMUM FILTERING. (3 cr; prereq grad in electrical engineering or ‡)
Stochastic processes, stationarity, independence, transformations of stochastic processes, ergodicity; correlation and power spectrum; the matched filter, the Wiener filter.

5703. MODULATION SYSTEMS. (3 cr; prereq 5702 or 5753)
Mathematical models and effects of noise on modulation systems such as AM, FM, PCM. Telemetry and space communication systems.

5704. SIGNAL DETECTION AND ESTIMATION THEORY WITH APPLICATIONS. (3 cr; prereq 5702 or ‡)
Risk theory approach to detection and estimation. Binary and multiple alternative detection of phase, frequency, and epoch time of signal. Applications to current electronic systems.

5750-5751. SYSTEM ANALYSIS AND OPTIMUM CONTROL. (3 cr per qtr; prereq 5001 or equiv or ‡)
5750: Linear algebra and matrix differential equations; linear system representation; stability of linear systems via Lyapunov's Direct Method; structure of linear systems; controllability and observability, sensitivity analysis of linear systems. 5751: Problem formulation and mathematical modeling; variational techniques and perturbation theory; mathematical programming; game theory; geometric theory of optimum control.

5752. NONLINEAR SYSTEM DESIGN. (3 cr; prereq 5750 or ‡)
Graphical, approximate, analytical, and numerical techniques in nonlinear system analysis and design; stability of nonlinear systems. The use of computers in system design.

5753. LINEAR STOCHASTIC SYSTEMS. (3 cr; prereq grad standing or ‡)
Random signals in linear systems; linear filtering, prediction, and estimation; parameter estimation in identification problems; adaptive and learning systems.

5760. BIOLOGICAL SYSTEM MODELING AND ANALYSIS. (3 cr; grad standing or ‡)
Purposes of biological system modeling: advantages, limitations, and special problems. Models of nerve excitation and propagation. Biological control systems: respiratory system, cardiovascular system. Sensory organs and various theories of perception. Limbs and locomotion. Biofeedback.

5800-5801. POWER SYSTEM ANALYSIS. (3 cr per qtr; prereq 5500 or equiv, 5750, CICS 5301 or ‡)
Matrix representation of large power systems. Formulation and modification of network matrices. Numerical and computer methods of solution. Applications to fault calculations, load-flow studies, stability studies, and loss formulas.

5851-5852-5853. DIGITAL COMPUTER SYSTEMS. (3 cr per qtr; prereq grad standing or ‡)
5851: Boolean analysis and synthesis with practical logic circuits. Sequential circuit theory and practical design techniques. Switching hazards and races. 5852: Digital systems design. Flow charts and bar charts. Clock generation and control. Interregister transfer control. Sequence counter design. 5853: Digital computer design. Instruction classes and sequences. Memory systems. Digital arithmetic system design. Input-output techniques.

FOR GRADUATE STUDENTS ONLY

8000, 8001, 8002. ADVANCED TOPICS IN NETWORK THEORY

8090. SEMINAR: ELECTRONICS

8100-8101-8102. PROBLEMS IN ELECTROMAGNETISM

8110-8111-8112. PLASMA PHYSICS

8120-8121-8122. FUNDAMENTALS OF ACOUSTICS

8140. SEMINAR: PLASMA PHYSICS

8143. SEMINAR: MODERN OPTICS

8150-8151. SOLID STATE PHYSICS

8152. MAGNETIC PROPERTIES OF SOLIDS

8153-8154-8155. PROPERTIES OF SEMICONDUCTORS

8156-8157-8158. FERROMAGNETISM AND RELATED PHENOMENA

8160-8161-8162. QUANTUM ELECTRONICS

8170-8171-8172. FLUCTUATION PHENOMENA
8190. SEMINAR: QUANTUM ELECTRONICS
8191. SEMINAR: SURFACE PHYSICS
8200-8201-8202. TOPICS IN STATISTICAL THEORY OF COMMUNICATION
8240. SEMINAR: COMMUNICATION
8250-8251-8252. ADVANCED CONTROL TOPICS
8253. LARGE-SCALE SYSTEM MODELS
8254. STRUCTURAL TECHNIQUES IN ANALYSIS AND CONTROL OF LARGE-SCALE SYSTEMS
8255. CONTROL AND OPTIMIZATION IN LARGE-SCALE SYSTEMS
8260-8261-8262. NONLINEAR SYSTEMS
8290. SEMINAR: CONTROL THEORY
8291. SEMINAR: SYSTEM THEORY
8300-8301-8302. ADVANCED POWER SYSTEM TOPICS
8340. SEMINAR: ELECTRIC POWER
8341. SEMINAR: ENERGY CONVERSION
8350. MODELS FOR COMPUTING MACHINES
8351. ADVANCED COMPUTER SYSTEMS
8352. ADVANCED SWITCHING THEORY
8450. SPECIAL INVESTIGATIONS
8451. ADVANCED TOPICS IN ELECTRICAL ENGINEERING

Engineering Graphics (EG)

0001. THE SLIDE RULE. (1 cr [no cr for students registered in IT]; prereq higher algebra and trigonometry recommended; 1 lect hr per wk)
Computation practice and theory. Design of special scales.

1025. ENGINEERING GRAPHICS. (4 cr; prereq ¶Math 1211 or equiv recommended; 3 lect, 1 rec, and open lab hrs per wk)
Engineering representation and analysis of systems of projection; the coordinate system, graphical and parallel numerical and computer solutions of space problems, intersections, and developments. Techniques of sketching; pictorial projection systems, size description, standard and simplified practices applied to graphic communication.

1026, 1027†. ENGINEERING GRAPHICS. (2 cr per qtr, §1025; 2 lect hrs per wk and open lab hrs)
Equivalent to EG 1025 but taught over a period of 2 quarters.

3028. GRAPHICAL COMPUTATION AND EMPIRICAL ANALYSIS. (4 cr; prereq Math 1221 and Phys 1271 or equiv recommended; 3 lect hrs per wk, open lab)
Graphical computation of engineering problems involving algebra, calculus, and basic physical relationships. Functional scales, nomography and the derivation of empirical equations correlating graphic, algebraic, and computer methods.

3029. GRAPHICAL COMMUNICATION AND ILLUSTRATION FOR DESIGN. (4 cr; prereq 1025 or equiv recommended; 3 lect hrs per wk, open lab)
Engineering representation in one-view and multiview systems. Dimensioning systems. Graphical approach relating functional design to space requirements. Pictorial representation and the principles and techniques of shading. Sketching.

5194. GRAPHICS IN ENGINEERING. (2-4 cr; prereq 1025 or equiv recommended; hrs ar)
A synthesis and extension of the procedures of grapical mathematics, nomography and/or descriptive geometry as applied to solutions of complex problems within the individual student's area of interest pursued as an individualized project and usually resulting in a comprehensive report.

Geo-Engineering (GeoE)

1001. GEO-ENGINEERING LABORATORY. (1 cr)
The field of geo-engineering and closely associated fields of mineral engineering described and discussed in lectures and laboratories.

3012. GEO-ENGINEERING SURVEYING. (2 cr; prereq CE 3100 or ‡)
Mine and geologic field survey control systems. Triangulation, stadia, plane table. Compass surveys. Drill hole and joint systems surveys. Point and stereo diagrams. Underground mine survey control, meridian transfer, gyrotheodolite, stope surveys, special problems.

3015. SURVEY FIELD WORK. (2 cr; prereq 3012; hrs ar)
Open pit and underground surveying, shaft plumbing, stripping estimates; plane table work; solar and stellar observations; special problems.

5180. GEOCHEMICAL EXPLORATION. (3 cr; prereq sr or ‡)
Geochemical principles and techniques involved in the search for orebodies. Basic premises, primary and secondary distribution halos, Eh-pH, geochemical provinces, interpretation of data, case studies. Laboratory work on colorimetric analysis of rock, soil, water.

5190. SELECTED TOPICS IN MINERAL EXPLORATION. (3 cr; prereq sr, grad)
Exploration programming in relation to theories of ore genesis. Analyses of effects of contract and lease requirements on decision and planning. Statistical analyses in ore estimates. Case histories. Special problems.

5216. GEO-ENGINEERING AND ROCK MECHANICS I. (4 cr)
Site plans, geologic defects, rock properties, geophysical methods, vibration damage criteria, design of rock mass improvement systems including rock bolting, prestressing, and grouting. Cleft-water pressures, case histories. Elementary analysis of stress and strain in rock.

5218. TUNNEL TECHNOLOGY. (3 cr; prereq 5330 or ‡)
Tunneling systems, site problems. Analysis of stress and load. Design of linings and support. Material handling. Planning. Special problems. Case histories.

5260-5262. GEO-ENGINEERING ANALYSIS. (2 cr for 5260, 3 cr for 5262; prereq sr or ‡; 2 lab hrs per wk for 5260, 6 lab hrs per wk for 5262)
Comprehensive analysis of a geological engineering or rock mechanics problem. Involves the integration of concepts of rock and soil mechanics, geology and geophysics, mineral engineering and economics, in a specific problem chosen by the student and staff. Preparation of a professional report.

5330. GEO-ENGINEERING AND ROCK MECHANICS II. (4 cr)
Design of blasting patterns and control of blast damage in rock, stress in room and pillar systems, foundations for structures, in situ stress measurements, disintegration, and comminution.

5332. DISINTEGRATION AND EXCAVATION OF ROCK. (4 cr)
Drilling, blasting, thermal fragmentation, crushers, and mills, and methods of product classification.

5334. ROCK MECHANICS. (4 cr; prereq 5330 or ‡)
Mechanical behavior of jointed rock masses, rock slope stability, influence of groundwater, rock bolting, field determination of rock properties, analog and digital computer simulation in rock mechanics.

5437. COMPUTER APPLICATIONS IN GEO- AND MINERAL ENGINEERING. (4 cr)
Finite differences applications in ore-reserve estimates, volume of fill, haulage heat transfer, and fluid flow. Solution linear equations, curve fitting, regressions analysis and iterative methods to structural and ventilation analysis. Introduction to random numbers, simulation and computer models.

5660. SPECIAL GEO-ENGINEERING PROBLEMS. (Cr and hrs ar; prereq sr or ‡)
Literature survey, research work or design study in geo-engineering problems.

FOR GRADUATE STUDENTS ONLY

8336. ANALYTICAL METHODS IN ROCK MECHANICS

8350-8352. ADVANCED ROCK MECHANICS I, II

8601-8602-8603. SEMINAR: GEO-ENGINEERING

8604-8605-8606. SEMINAR: GEO-ENGINEERING

8612-8613-8614. GEO-ENGINEERING RESEARCH PROBLEMS

Geology and Geophysics (Geo)

1001f,w,s. PHYSICAL GEOLOGY. (5 cr; 3 lect hrs, one 2-hr lab, 1 rec hr per wk) Staff
A first course in geology; introduction to scientific method and nature of the earth; main features of the physical world, and processes that have formed them.

1001H. HONORS SECTION: PHYSICAL GEOLOGY. (5 cr)
A special course for nonscience majors. Taught on an informal basis by senior faculty; provides an introduction to the world of geology. In addition to lectures there will be field trips and special lab problems.

1002f,w,s. HISTORICAL GEOLOGY. (4 cr; 3 lect hrs and one 2-hr lab per wk) Sloan
Evolution of earth from its origin to present; special attention to succession of physical and biological events of past 600 million years.

1007s. ENVIRONMENTAL GEOLOGY. (4 cr, §1008; prereq 1001)
Geological application in resource management, land use planning, technology, and conservation. Geological evolution of the biosphere and the impact of man's activities on land, sea, and air resources. Geological hazards. The Twin Cities metropolitan areas as a geological environment. Lectures, labs, and field trips.

1008w. GEOLOGY AND MAN. (4 cr, §1007)
An introductory course concerned with man in his physical environment; geological hazards (e.g., earthquakes); the nature and use of natural resources; geological aspects of pollution, recreation, and land use; the effect of the composition of rocks and soils on nutrition and disease.

1011w. DRIFTING CONTINENTS. (4 cr; 3 lect hrs and one 2-hr lab per wk) Sawkins, Chase
Introduces the student to a set of concepts that have completely revolutionized geological thinking. These concepts allow the integration of many diverse geological elements, e.g., volcanoes, earthquakes, mountain chains, wandering continents, and earth resources.

1012f. EARTH AS A PLANET. (4 cr; 3 lect and 1 lab hrs per wk) Murthy
A survey course dealing with the origin and evolution of the earth, its structure and composition in relation to other planets and the cosmic abundances and mode of formation of elements in the solar system.

1013f. ORIGIN AND EVOLUTION OF LIFE. (4 cr; 3 lect and 1 lab hrs per wk) Sloan
Geological evidence of the origin and increasing complexity of living systems, including biogenesis, single-celled organisms, plants, animals, and ecosystems. Problems of extraterrestrial life.

1111f. INTRODUCTORY PHYSICAL GEOLOGY. (5 cr; for prospective majors and others desiring more intensive lect and lab sequence than 1001; prereq high school or college chemistry or #; 3 lect hrs, 1 rec hr, and two 2-hr labs per wk) Weiblen

1601w,s. OCEANOGRAPHY. (4 cr; prereq high school physics and chemistry recommended; 4 lect hrs per wk) Normark, Shapiro
A survey of the marine sciences including marine geology, physical oceanography, chemistry of the seas, biological oceanography, resources of the sea, and career opportunities in oceanography and related fields.

1602w,s. OCEANOGRAPHY. (5 cr; prereq high school physics and chemistry recommended; 4 lect hrs and 2-hr lab per wk) Normark, Shapiro
Same as Geo 1-601 but with added laboratory.

3014s. EARTH MATERIALS AND RESOURCES. (4 cr; prereq 1 qtr each of chemistry and physics) Hall, Banerjee
A survey course on the crystal chemistry and physics of earth materials. Subjects covered include crystal chemistry of oxides, carbonates and silicates, phase relations of minerals, mineral physics, processes of formation of igneous, sedimentary, and metamorphic rocks, and materials and structure of the earth's interior.

3099f,w,s. PROBLEMS IN GEOLOGY AND GEOPHYSICS. (1-6 cr; prereq ♯ and △)
Individual research or problem selected on the basis of individual interests and background.

3101f. SURFICIAL GEOLOGIC PROCESSES. (5 cr; prereq 3401 or ♯)
Geological processes acting at the surface of the earth. Topics include geomorphology, limnology, groundwater geology, and sedimentology. Field trips.

3102s. PETROLOGY. (5 cr; prereq 3401 or ♯) Weiblen
Introduction to the lithologic character and genesis of igneous and metamorphic rocks.

3103s. STRUCTURAL GEOLOGY. (5 cr; prereq 3102 or ♯) Hudleston
Primary and secondary structures of rocks; mechanics and modes of deformation, and an introduction to field methods in geology. Field trips.

3112s. EARTH HISTORY. (5 cr; prereq 1111 or ♯; 3 lect hrs, 1 rec hr, two 2-hr labs per wk) Swain
For prospective majors and others desiring more intensive course than Geo 1002.

3201. SEMINAR: CONTINENTAL DRIFT. (5 cr; prereq 1001 and 1002, or 1111 and 3112) Chase, Sawkins, Sloan
Use of synthesis of regional geology and geophysics to study past configurations of the continents and timing of their breakup and collision. Introductory lectures, readings, seminar presentations by students, term paper.

3401w. INTRODUCTORY MINERALOGY. (5 cr; prereq 1001 or 1111 or ♯, 1 term college chemistry, Math 1441; 3 lect and 6 lab hrs per wk) Stout
Introduction to crystallography, crystal chemistry, and mineralogy. Descriptive and determinative mineralogy. Study of minerals in natural rock systems.

5002s. STRUCTURAL GEOLOGY. (4 cr, §3103 or equiv; not open to geology, geophysics, geo-engineering, mineral resources engineering, and metallurgy-materials science majors; prereq 3401 or 5004 or ♯; 3 lect and 2 lab hrs per wk) Hudleston
Primary and secondary structures of rocks, mechanics and modes of deformation, and structural techniques. Laboratory exercises in three-dimensional representation and solution of selected structural problems.

5004w.* MINERALOGY. (4 cr, §3401; not open to geology, geophysics, and geological, mineral, and metallurgical engineering majors; open to agriculture and forestry students and postgrad students in education; prereq 1001 or 1111 or ♯...1 term college chemistry, Math 1441; 3 lect and 6 lab hrs per wk) Stout
Introduction to crystallography, crystal chemistry, and mineralogy. Descriptive and determinative mineralogy. Study of minerals in natural rock systems.

5051su. PHYSICAL GEOLOGY FOR TEACHERS. (4 cr, §1001, §1111; open only to students holding degrees in education; prereq 1 term college chemistry or physics)
Introduction to scientific methods and nature of the earth. Survey: main features of physical world and processes that have formed them.

5052su. HISTORICAL GEOLOGY FOR TEACHERS. (4 cr, §1002, §1112; open only to students holding degrees in education; prereq 1001 or 1111 or 5051 or ♯; laboratory, field work, and seminar)
Introduction to origin of the earth, physical evolution of its crust through geological time, and biological changes that occurred during its history.

5102.* PHYSICAL STRATIGRAPHY. (4 cr; prereq 3103) Swain
Lectures, readings, discussions of modern literature, and lab work on Paleozoic, Mesozoic, and Cenozoic stratigraphy; geosynclinal and shelf development, oceanic and lacustrine deposits.

5108w. ADVANCED ENVIRONMENTAL GEOLOGY. (4 cr; prereq geology core curriculum 1111 through 3103 or equiv) Parham
Study of man's impact on the geological environment as well as the effect of geology/geologic processes on man. Topics include land-use planning, geologic hazards, geologic aspects of health and disease, mineral conservation, waste disposal, and geologic controls and limitations in developed versus underdeveloped countries.

5110su. FIELD GEOLOGY. (9 cr; open only to students majoring in geology, geophysics, and geo-engineering; prereq 3103 and ♯)
Measurement of stratigraphic sections; study of fossils and igneous, sedimentary, and metamorphic rocks. Geological surveying on aerial photographs and topographic maps. Preparation of geologic maps and cross sections. Study of structural and geomorphic features and geologic setting of mineral deposits.

5151f. INTRODUCTION TO PALEONTOLOGY. (5 cr; prereq 1002 or 3112 or ‡) Sloan
Introduction to morphology and classification of major fossil groups.

5152. INVERTEBRATE PALEONTOLOGY. (5 cr; prereq 5151; 3 lect and 4 lab hrs per wk; offered when demand warrants) Staff
Detailed studies of morphology, classification, and ecology of selected groups of invertebrate fossils.

5154w. VERTEBRATE PALEONTOLOGY I. (5 cr; prereq 5151 or Zool 5124) Sloan
Morphology, evolution, and stratigraphic distribution of fossil fish, amphibians, reptiles, and birds.

5155s. VERTEBRATE PALEONTOLOGY II. (5 cr; prereq 5154 or Zool 5124) Sloan
Morphology, evolution, and stratigraphic distribution of fossil mammals.

5251s.° GEOMORPHOLOGY. (5 cr; prereq 1001, Math 1111...Geo 3101 required and 3401 recommended for geology majors...or ‡) Hooke
A quantitative study of landform processes in various regions of the earth and on the surfaces of other planets. Topics: weathering, slope and shore processes, fluvial erosion and deposition, wind action, impact phenomena and tectonics. Field trips first, fifth, seventh, and ninth Saturdays. Term project.

5261f.° GLACIAL GEOLOGY. (4 cr [5 cr with term paper]; prereq 1002 or 3112) Wright
Formation and characteristics of modern glaciers; erosional and depositional features of Pleistocene glaciers; history of Quaternary environmental changes in glaciated and nonglaciated areas. Field trips.

5301. CHEMICAL EQUILIBRIA IN THE EARTH. (3 cr; prereq Chem 5501 or 5520 or ¶) Hall
Recitation-problems course dealing with the application of thermodynamics and kinetics to chemical systems in the earth sciences. Included are reactions in natural gases, solid-state mineral transformations, melting and solid-solution phenomena, rates of nucleation and mineral growth, and reactions in natural waters.

5302s.° GEOCHEMISTRY. (4 cr; prereq Chem 5502 and Geo 5506 or ¶) Murthy
The origin and chemical evolution of the earth through geologic time, by detailed studies of the distribution of major and minor elements in the crust, mantle, and the core of the earth. Nature of element fractionation processes in major geologic processes.

5351f.° METAL SULFIDE DEPOSITS. (5 cr; prereq 3401, 3103 or ‡) Sawkins
Nature and distribution of sulfide deposits, and analysis of the processes by which metals are concentrated in magnetic, hydrothermal, and sedimentary environments.

5401s.° CRYSTAL CHEMISTRY OF MINERALS. (4 cr; prereq 3401, 1 yr college chemistry; 3 lect and 2 lab hrs per wk) Zoltai
Basic concepts of symmetry, packing, coordination, and bonding of atoms in crystal structures. Classification and discussion of crystal structures and crystal chemistry of minerals.

5452s.° IGNEOUS AND METAMORPHIC PETROLOGY. (4 cr; prereq 3102, Chem 5502 or 5521, Math 3211 or ‡) Stout
Rock associations, textures, and structures of world-wide igneous provinces and metamorphic terranes. Petrogenesis in light of phase equilibria, experimental studies, and current interpretations. Laboratory and term paper.

5505f. PHYSICS AND CHEMISTRY OF THE EARTH I. (4 cr; prereq 1111 and Phys 1295) Mooney
Earthquake seismology; physical structure of the earth's crust and deep interior.

5506w. PHYSICS AND CHEMISTRY OF THE EARTH II. (4 cr; prereq 5505 or ‡) Murthy
Origin and chemical evolution of the earth through geologic time.

5507s. PHYSICS AND CHEMISTRY OF THE EARTH III. (4 cr; prereq 5506 or ‡) Banerjee, Chase
Gravity and magnetic fields of the earth; paleomagnetism, thermal history of the earth.

5511f.° PRINCIPLES OF GRAVITY AND MAGNETIC EXPLORATION. (3 cr; prereq Phys 1291) Chase
Instrumentation, surveying techniques, reduction of data, interpretation, case histories.

5512w.* PRINCIPLES OF SEISMIC EXPLORATION. (3 cr, §5522; prereq Phys 1291) Mooney
Reflection and refraction seismology; theory, interpretation, instruments.

5513s.* PRINCIPLES OF ELECTRICAL EXPLORATION. (3 cr; prereq Phys 1291) Mooney
Resistivity, electromagnetic, induced polarization, and other methods.

5522w. PRINCIPLES OF REFRACTION SEISMIC EXPLORATION. (2 cr, §5512; primarily for civil engineering and geo-engineering students; prereq Phys 1291) Mooney
Seismic wave theory; refraction seismology.

5541f.* GEOMAGNETISM. (3 cr; prereq 3 qtrs geology, physics, mathematics) Banerjee
Present geomagnetic field on the Earth's surface, its time variation and westward drift, origin of field in terms of a geomagnetic dynamo, behavior of the ancient field including reversals from the paleomagnetic record, continental drift, and seafloor spreading.

5601f. LIMNOLOGY. (4 cr, §Ecol 128; prereq Chem 1005 or equiv and ‡) Shapiro
Description and analysis of events occurring in lakes, reservoirs, and ponds, beginning with their origins and progressing through study of their physics, chemistry, and biology. Emphasis on interrelationships of these parameters, and on effects of civilization on lakes. Laboratory, field trips.

5611s. GROUNDWATER GEOLOGY. (3 cr; prereq 1001 or 1111, Math 1231, 1 qtr physics and chemistry or ‡) Pfannkuch
Origin, occurrence, and movements of groundwater. Characteristics of major aquifers and aquitards. Exploratory investigations. Hydrogeologic units and boundaries. Principles and theoretical aspects of recharge. Quality of groundwater supplies.

5642f. INTRODUCTORY MARINE GEOLOGY. (4 cr; prereq upper division geology major or grad student and one of: 1111, 3112, 3401, 3201 or 3651 or ‡)
Physiography and structure of ocean basins and continental margins with particular consideration of their development as suggested by the concepts of new global tectonics. A review of marine geological and geophysical techniques is included.

5652s.* SEDIMENTOLOGY. (4 cr; prereq 3101, 3102, 3103 and 5642 or ‡) Normark
Sedimentary processes and products with particular emphasis on modern marine depositional environments. Special consideration of clastic sedimentation on continental margins.

FOR GRADUATE STUDENTS ONLY (OR) SENIORS WITH SPECIAL PERMISSION

A. General Geology

8008. SEMINARS IN CURRENT TOPICS IN GEOLOGY

8103. MARINE BIOSTRATIGRAPHY

8128. SEMINAR: STRATIGRAPHY

8152. ADVANCED INVERTEBRATE PALEONTOLOGY

8156. MARINE MICROPALEONTOLOGY

8158. SEMINAR: PALEONTOLOGY

8159. RESEARCH IN PALEONTOLOGY

8161. PALEOECOLOGY

8168. SEMINAR: PALEOECOLOGY

8201. GEOTECTONICS

8202. ADVANCED STRUCTURAL GEOLOGY

8208. SEMINAR: STRUCTURAL GEOLOGY

8209. RESEARCH IN STRUCTURAL GEOLOGY

8219. RESEARCH IN STRATIGRAPHY

8258. SEMINAR: GEOMORPHOLOGY

8259. RESEARCH IN GEOMORPHOLOGY
8262. PLEISTOCENE GEOLOGY
8268. SEMINAR: PLEISTOCENE GEOLOGY
8269. RESEARCH IN PLEISTOCENE GEOLOGY

B. Mineralogy and Petrology

8308. SEMINAR: GEOCHEMISTRY
8309. RESEARCH IN GEOCHEMISTRY
8351. ADVANCED MINERAL DEPOSITS I
8352. ADVANCED MINERAL DEPOSITS II
8355. GEOLOGY OF FERROUS METAL AND NONMETALLIC DEPOSITS
8358. SEMINAR: MINERAL DEPOSITS
8359. RESEARCH IN MINERAL DEPOSITS
8361. MINERAL FUEL DEPOSITS
8402. X-RAY MINERALOGY
8404. X-RAY CRYSTALLOGRAPHY
8408. SEMINAR: MINERALOGY AND CRYSTALLOGRAPHY
8409. RESEACH IN MINERALOGY AND CRYSTALLOGRAPHY
8419. SEMINAR: CLAY MINERALOGY
8453. PHASE EQUILIBRIA IN MINERAL SYSTEMS
8454. IGNEOUS PETROLOGY
8455. METAMORPHIC PETROLOGY
8458. SEMINAR: PETROLOGY
8459. RESEARCH IN PETROLOGY

C. Hydrogeology

8311. ORGANIC GEOCHEMISTRY
8318. SEMINAR: ORGANIC GEOCHEMISTRY
8602. ADVANCED LIMNOLOGY
8603. METHODS FOR ANALYSIS OF NATURAL WATERS
8608. SEMINAR: LIMNOLOGY
8609. RESEARCH IN LIMNOLOGY
8612. ANALYTICAL GEOHYDROLOGY
8618. SEMINAR: GROUNDWATER GEOLOGY
8619. RESEARCH IN GROUNDWATER GEOLOGY
8642. MARINE GEOLOGY
8649. RESEARCH IN MARINE GEOLOGY
8651. SEDIMENTARY GEOCHEMISTRY
8658. SEMINAR: SEDIMENTOLOGY
8659. RESEARCH IN SEDIMENTOLOGY

D. Geophysics

8521. LINEAR DATA PROCESSING WITH GEOPHYSICAL APPLICATIONS

8531-8532. THEORY OF ELASTIC WAVE PROPAGATION I, II

8542. PRINCIPLES OF ROCK MAGNETISM

8562. STUDIES OF THE CRUST AND UPPER MANTLE

8568. SEMINAR: GEOPHYSICS

8569. RESEARCH IN GEOPHYSICS

Industrial Engineering/Operations Research (IEOR)

5000. INTRODUCTION TO INDUSTRIAL ENGINEERING ANALYSIS. (4 cr; prereq Math 1231...ME 3900 recommended; 3 lect and 1 rec hrs per wk)
Scientific management, mathematical models, methods engineering, work measurement, worker satisfaction and participation, wage payment plans, breakeven analysis, incremental costs, the time value of money and the present value concept; cost quality and inventory control; production scheduling, plant locations, and layout; linear programming, PERT, and the systems approach to management problems.

5010. INTRODUCTION TO WORK ANALYSIS. (4 cr; prereq 5000; 3 lect and 1 rec hrs per wk)
Fundamentals of methods engineering, work measurement, and plant layout; charting techniques, process charts, predetermined time systems, work sampling, time study, master standard data, cross charting, and line balancing.

5020. ENGINEERING COST ACCOUNTING, ANALYSIS, AND CONTROL. (4 cr; prereq ME 3900 and IEOR 5000 recommended; 3 lect and 1 rec hrs per wk)
Basic accounting concepts, financial statements, analysis and control of current assets such as cash, receivables, and inventory; income tax planning, cost analysis, standard costs for product costing, time value of money, quantification of risk and uncertainty, utility theory, cost of capital and capital structure, capital budgeting under capital rationing, management decision, and investment decisions.

5030. QUALITY CONTROL AND RELIABILITY. (4 cr; prereq Math 1231 and ME 3900... IEOR 5000 recommended; 3 lect and 1 rec hrs per wk)
History of quality control, quality policies and objectives, economics of quality, design for system effectiveness, reliability and maintainability, statistical aids to reliability, quality specifications, inspection, acceptance sampling, vendor relations, process control, motivation for quality, quality assurance, and quality control engineering.

5040. INTRODUCTION TO OPERATIONS RESEARCH. (4 cr; prereq Math 1231...IEOR 5000 recommended; 3 lect and 1 rec hrs per wk)
Linear programming, algebra and geometry of linear models, simplex method, sensitivity testing, and duality; network models, network algorithms, and dynamic models.

5180, 5181. APPLIED INDUSTRIAL ENGINEERING. (3-5 cr [1-2 cr term paper option]; prereq 5000, 5010, 5020, 5030 and 5040; 3 lect hrs per wk)
Industrial engineering surveys and programs, case problems, studies in local plants.

5221. INDUSTRIAL PLANTS. (4 cr; prereq 5010; 3 lect and 1 rec hrs per wk)
Layout of production and service facilities in manufacturing operations, analysis of materials flow, development of materials handling systems, and industrial packaging techniques.

5311. MANAGEMENT FOR ENGINEERS. (3-5 cr [1-2 cr term paper option]; prereq 5000; 3 lect hrs per wk)
Historical development of management concepts; organizational systems and authority relationships; planning, communication and management responsibility.

5321. INDUSTRIAL SAFETY. (3-5 cr [1-2 cr term paper option]; prereq 5000 recommended; 3 lect hrs per wk)
Definition and philosophy of safety, safety training, safety requirements for production processes, equipment and plants, industry standards, safety devices, and product safety.

5351. ANALYSIS OF PRODUCTION PROCESSES. (3-5 cr [1-2 cr term paper option]; prereq 5020...5000, 5010, 5030 and 5040 recommended; 3 lect hrs per wk)
A case course of problems in production engineering and production management. Analysis of production problems from selected industries. Emphasis is placed on the development of ability to recognize and diagnose industrial problems.

5361. INVENTORY AND PRODUCTION CONTROL. (4 cr; prereq ME 3900, IEOR 5000 and 5040; 3 lect and 1 rec hrs per wk)
Forecasting techniques and the analysis of inventory systems, aggregate planning, capacity decision, scheduling techniques, line balancing, use of linear programming models in the design, operation, and control of production and distribution systems.

5441. OPERATIONS RESEARCH II. (4 cr; prereq Math 1231, ME 3900, and IEOR 5040; 3 lect and 1 rec hrs per wk)
Dynamic programming, integer programming, nonlinear and probabilistic models.

5442. OPERATIONS RESEARCH III. (4 cr; prereq 5441; 3 lect and 1 rec hrs per wk)
Optimization in probability models, Markov chains, queueing theory, and simulation.

5445. TOPICS IN MANAGEMENT SCIENCE. (3-5 cr [1-2 cr term paper option]; prereq 5010, 5020, 5030, and 5040 recommended; 3 lect hrs per wk)
Specialized topics in management science. Analytical tools for decision making and management of the production function. Emphasis on topics appearing in the current literature. Topical coverage changes from quarter to quarter.

5531. INDUSTRIAL SAMPLING TECHNIQUES. (4 cr; prereq ME 3900, IEOR 5030; 3 lect and 1 rec hrs per wk)
An in-depth coverage of industrial sampling plans. Single, double, and multiple sampling plans; sequential, continuous, and variable sampling plans; life testing plans; administrative and economic considerations.

5550. DESIGN AND ANALYSIS OF EXPERIMENTS I. (4 cr; prereq ME 3900 or Stat 3091 or 5121 or 5131 or equiv; 3 lect and 1 rec hrs per wk)
One-factor experiments, analysis of variance, estimation and comparison of effects, orthogonal contrasts, fixed, random, and mixed models, incomplete block design.

5551. DESIGN AND ANALYSIS OF EXPERIMENTS II. (4 cr; prereq ME 3900, IEOR 5550; 3 lect and 1 rec hrs per wk)
Two- or more-factor experiments. Designs involving crossed, nested, and mixed classifications; orthogonal polynomials; block confounding; fractional factorial designs; and computer programs for analysis.

FOR GRADUATE STUDENTS ONLY

8110-8111-8112. ADVANCED INDUSTRIAL ENGINEERING

8310-8311-8312. PRODUCTION ENGINEERING PROBLEMS

8410-8411-8412. INDUSTRIAL ENGINEERING RESEARCH

8420. LINEAR PROGRAMMING

8440. DYNAMIC PROGRAMMING

8450. QUEUEING THEORY

8460. STOCHASTIC PROGRAMMING

8470. ADVANCED INVENTORY AND PRODUCTION CONTROL

Landscape Architecture (LA)

1001f. ENVIRONMENTAL DESIGN: MAN AND ENVIRONMENT. (4 cr, §Arch 1001)
See Arch 1001 for description.

1002w. ENVIRONMENTAL DESIGN: TOOLS AND PROCESSES. (4 cr, §Arch 1002; prereq 1001)
See Arch 1002 for description.

1003s. ENVIRONMENTAL DESIGN: IMPLEMENTATION AND EVALUATION. (4 cr, §Arch 1003; prereq 1002)
See Arch 1003 for description.

1021f. HISTORY OF ENVIRONMENTAL DEVELOPMENT: ARCHITECTURE. (4 cr, §Arch 1021; 4 lect hrs per wk)
See Arch 1021 for description.

1022w. HISTORY OF ENVIRONMENTAL DEVELOPMENT: LANDSCAPE ARCHITECTURE. (4 cr, §Arch 1022; prereq 1021; 4 lect hrs per wk)
See Arch 1022 for description.

1023s. HISTORY OF ENVIRONMENTAL DEVELOPMENT: PLANNING. (4 cr, §Arch 1023; prereq 1022; 4 lect hrs per wk)
See Arch 1023 for description.

1024. LANDSCAPE THEORY. (4 cr; 3 lect and 3 lab hrs per wk)
Analysis of design elements and forms involving direction, shape, proportion, and color, with emphasis on their function in design; a study of perception and man's relationship to his environment, and the social effects and psychological basis for design.

1025. BASIC VISUALIZATION. (4 cr; 2 lect and 4 lab hrs per wk)
Perspective drawing, landscape sketching, visual analysis of landscape materials, presentation techniques for plans, sections, and elevations.

1031. INTRODUCTION TO LANDSCAPE ARCHITECTURE. (4 cr; 4 lect hrs per wk)
Analysis of design potential of materials of the landscape; exercises in critical assessment of land developments and detail landscapes; exploration of the role of the landscape architect in shaping the natural and cultural environment; brief historical review of site developments.

3071, 3072, 3073. LANDSCAPE TECHNOLOGY I. (4 cr per qtr; prereq CE 3100; 2 lect and 6 lab hrs per wk)
Lectures, exercises, and projects in ground form manipulation, earthwork, computation, and drainage techniques; layout of circulation and landscape utilities systems; land analysis procedures and techniques.

3075. LANDSCAPE TECHNOLOGY II. (4 cr; 2 lect and 6 lab hrs per wk)
Lectures, exercises, and projects in materials and construction techniques and working document preparation.

3081-3082-3083. BASIC DESIGN. (6 cr per qtr; prereq LA student; 1 lect and 15 lab hrs per wk)
Lectures and projects which begin to expand awareness of the design potential of environment, develop processes and graphic techniques for problem solving, begin a search toward developing methods of presenting ideas verbally and visually. Design of small-scale site systems with simple variables.

3091-3092. INTERMEDIATE DESIGN. (6 cr per qtr; prereq 3083; 2 lect and 12 lab hrs per wk)
Lectures and projects in exploration of the design potential of natural land materials, exploration of landscape survey and analysis techniques, assessment of the elements of environment as they condition design potential, exploration of methodologies for solving design problems, exploration of methods of expressing landscape form both geographically and through models; design of site systems with simple variations.

3093. DETAIL SITE DESIGN. (6 cr; prereq 3092)
Design of small-scale site systems with complex variables.

3096. SPECIAL PROBLEMS IN LANDSCAPE ARCHITECTURAL HISTORY. (1-6 cr; prereq #)

3097. SPECIAL PROBLEMS IN LANDSCAPE ARCHITECTURAL THEORY. (1-6 cr; prereq #)

3098. SPECIAL PROBLEMS IN LANDSCAPE ARCHITECTURAL DESIGN. (1-6 cr; prereq #)

3099. SPECIAL PROBLEMS IN LANDSCAPE ARCHITECTURAL TECHNOLOGY. (1-6 cr; prereq #)

3101. COMMUNICATING LANDSCAPE QUALITY. (3 cr; 1 lect and 6 lab hrs per wk; prereq 3093 or #)
Lectures and exercises in drawing techniques focused on developing graphic skills for designers working predominantly with exterior environments.

5010. PRINCIPLES OF OUTDOOR RECREATION DESIGN AND PLANNING. (4 cr; 4 lect hrs per wk)
For advanced students associated with design, management, and planning of recreation facilities. Planning and design principles related to recreational land use and development; parks, campsites, water areas, highways, summer and winter recreational facilities.

5101-5102. SITE PLANNING AND DESIGN I AND II. (6 cr per qtr; 2 lect and 12 lab hrs per wk)
Case study analysis and design of site organizational systems.

5103-5104. URBAN LANDSCAPE DESIGN I AND II. (6 cr per qtr; 2 lect and 12 lab hrs per wk)
Case study analysis and design of urban environments.

5105-5106. RECREATIONAL PLANNING AND DESIGN I AND II. (6 cr per qtr; prereq 5010; 2 lect and 12 lab hrs per wk)
Analysis development and presentation of landscape design solutions for diverse recreational land use.

5107-5108. REGIONAL LANDSCAPE DESIGN. (6 cr per qtr; prereq 3092; 3 lect and 12 lab hrs per wk)
Emphasis will be placed on the study of large-scale land areas. Analyzing development potential and evolving solutions for integration of divergent land use patterns such as agricultural, residential, commercial, industrial, and recreational.

5110. ADVANCED LANDSCAPE PLANNING AND DESIGN. (6 cr; prereq terminal qtr; 2 lect and 12 lab hrs per wk)
Advanced studies in area of students' option.

5115-5116. THEORY OF LANDSCAPE FORM AND STRUCTURE. (2 cr per qtr; prereq 3091 or ♯; 4 discussion hrs per wk)
Studies in landscape perception; lectures, discussions, and exercises in application of abstract design principles to the assessment of land developments; review of psychological and social implications of land developments; exploration of the design potential of landscape materials; investigation of contemporary problems in land development including all scales and types of land uses.

5121-5122. LANDSCAPE ARCHITECTURAL DESIGN. (6 cr per qtr; prereq ♯; 1 lect and 15 lab hrs per wk)
Research analysis and design of large-scale land development problems. Urban design and regional design collaboratives with fellow design professions and technical disciplines.

5123. LANDSCAPE ARCHITECTURAL THESIS. (12 cr; prereq terminal qtr; 36 lab hrs per wk)
Definition of a landscape problem; research and analysis of design potentials; projection of a solution to the problem to demonstrate proficiency in all phases of landscape architecture. Problem area to be selected in consultation with instructor.

5124. LANDSCAPE ARCHITECTURAL SEMINAR. (1 cr; prereq terminal yr of study)
Analysis of design principles and design goals in modern society. Review of current site development projects. Investigation in depth into specific areas of land development.

5131-5132-5133. SELECTED PROBLEMS IN LANDSCAPE ARCHITECTURE. (Cr ar; prereq ♯)

5175. LANDSCAPE TECHNOLOGY II. (4 cr; 2 lect and 6 lab hrs per wk)
Lectures, exercises, and projects in materials and construction techniques and working document preparation.

5226. PROFESSIONAL PRACTICE. (4 cr; prereq terminal yr of study)
Professional ethics, responsibility, and relations in business. Office management, preparation of professional communications, estimates, specifications, and contracts. Lectures, written exercises, and office visits.

5262. HISTORY AND LITERATURE OF LANDSCAPE ARCHITECTURE. (4 cr; 4 lect hrs per wk)
A search for design principles as expressed in landscape created by man from ancient times to the contemporary period. Specific focus on analysis of the visual form of environments as outgrowths of geographical, cultural, and technological determinants.

Mathematics (Math)

0006. ELEMENTARY ALGEBRA. (See *Evening Classes Bulletin*)

0007. PLANE GEOMETRY. (See *Evening Classes Bulletin*)

0008. SOLID GEOMETRY. (See *Evening Classes Bulletin*)

0009. PREPARATORY MATHEMATICS. (See *College of Liberal Arts Bulletin*)

0090. CALCULUS REFRESHER. (See *Evening Classes Bulletin*)

1001f-1002w. MATHEMATICS. (See *College of Liberal Arts Bulletin*)

1005f,w,s.-1006w,s. FOUNDATIONS OF ARITHMETIC. (See *College of Liberal Arts Bulletin*)

1008f,w,s. TRIGONOMETRY. (See *College of Liberal Arts Bulletin*)

1111f,w,s. COLLEGE ALGEBRA AND ANALYTIC GEOMETRY. (See *College of Liberal Arts Bulletin*)

1119w,s. MATHEMATICS OF INVESTMENT. (See *College of Liberal Arts Bulletin*)

1131f,w,s. FINITE MATHEMATICS. (See *College of Liberal Arts Bulletin*)

1141f,w,s. ALGEBRA, PROBABILITY, AND PRE-CALCULUS. (See *College of Liberal Arts Bulletin*)

1142f,w,s. INTRODUCTION TO CALCULUS. (See *College of Liberal Arts Bulletin*)

1201f,w,s. PRE-CALCULUS. (5 cr, §1111, §1141; for students who intend to take a calculus sequence but lack preparation; prereq high school higher algebra, high school trigonometry or 1008, mathematics placement score)
Inequalities, analytical geometry; complex numbers, binomial theorem; mathematical induction; functions and graphs; trigonometric, exponential, and logarithmic functions.

1211-1221-1231. ANALYSIS I-II-III. (5 cr per qtr; prereq grade of C or better in 1201 or high school higher algebra, trigonometry, geometry and mathematics placement score for 1211...grade of C or better in 1211 for 1221...grade of C or better in 1221 for 1231)
Analytical geometry and calculus of functions of one variable, applications. Infinite series and sequences.

1311-1321-1331. COMPUTER CALCULUS I-II-III. (5 cr per qtr; prereq grade of C or better in 1201 or high school higher algebra, trigonometry, geometry and mathematics placement score for 1311...grade of C or better in 1311 for 1321...grade of C or better in 1321 for 1331)
Content and description is essentially the same as 1211-1221-1231 and 1611-1621, plus topics in elementary computer programming. Much of the material is presented from a computing point of view.

1511f-1521w-1531s. HONORS CALCULUS. (5 cr per qtr; prereq △)
Calculus of functions of one variable with emphasis on theory. Emphasis on basic concepts and proofs; attention to computational aspects.

1611-1621. ANALYSIS I-II. (5 cr per qtr; prereq 4 yrs high school mathematics incl trigonometry and △...a grade of C or better in 1611 for 1621)
An accelerated sequence for high-ability students (continued in Math 3611-3621). The contents of Math 1211-1221-1231 will be covered in 1611-1621.

3057. ACTUARIAL SCIENCE PRINCIPLES. (*See College of Liberal Arts Bulletin*)

3061f,w,s. OPERATIONAL METHODS FOR LINEAR SYSTEMS. (4 cr; primarily for EE students; prereq 3211, 3221)
Fourier series and applications to differential equations. Fourier transform, mathematical properties, amplitude and phase spectra, energy. The Laplace transform, mathematical properties, elementary inversion techniques, applications to differential equations.

3066f,w,s. ELEMENTARY DIFFERENTIAL EQUATIONS. (4 cr, §3221, §5512, §5521; prereq 1431 or 1231 or equiv)
Elementary techniques of problem solving. First- and second-order equations, linear equations of higher order.

3071f-3072w-3073s. HISTORY OF MATHEMATICS. (2 cr per qtr; for students with general knowledge of mathematics and some curiosity about historical development of mankind; prereq for any qtr is 1431 or 1231)
Development of main branches of contemporary mathematics within framework of history of ideas as well as of techniques. Impact of thought of previous generations on modern developments. Term paper each quarter. 3071: Greek mathematics. 3072: Creation of calculus. 3073: Topics in history of mathematics.

3099. SEMINAR: MATHEMATICAL PROBLEMS: (4 cr; prereq 3211 and 3221 or equiv)
Problems ranging from elementary algebra and geometry through undergraduate mathematics.

3142f,w,s. INTRODUCTION TO LINEAR ALGEBRA. (4 cr, §3221, §3511; prereq 2 qtrs calculus)
Vectors, systems of linear equations, matrices, determinants, eigenvalues, applications. Emphasizes techniques but includes some proofs of theorems.

3161f,w,s. SYNTHETIC METRIC GEOMETRY. (4 cr; prereq 1211 or 1421 or equiv)
Euclidean geometry: ruler and compass constructions and theorems on triangle and circle not studied in high school plane geometry.

3211. ANALYSIS IV. (5 cr, §3411, §3521; prereq a grade of C or better in 1231 or equiv)
Partial differentiation, chain rule, implicit functions, applications. Multiple integrals in two and three dimensions.

3221f,w,s. INTRODUCTION TO LINEAR ALGEBRA AND LINEAR DIFFERENTIAL EQUATIONS. (5 cr, §3142, §3511; prereq 1231 or equiv)
Vectors, systems of linear equations, matrices, determinants, bases, eigenvalues. Linear differential equations and systems with constant coefficients, initial value problem and general solution, variation of parameters for inhomogeneous equations.

3231. VECTOR ANALYSIS. (4 cr, §5601-5602; prereq a grade of C or better in 3211 or equiv)
Scalar and vector products, derivatives, geometry of space curves, del operator, line and surface integrals, divergence and Stokes' theorem, transformation of coordinates, dyadics, applications. Mostly a technique course, intended mainly for students whose interests are not theoretical but who wish to learn the relevant mathematical facts and methods.

3511f,w,s. ANALYSIS IV. (4 cr, §3142, §3221; primarily for math majors, and math majors in the College of Education; prereq 1231, 1331, 1531 or 1621)
Abstract approach to study of finite dimensional vector spaces. Linear independence, linear transformations, matrices and determinants.

3521f,w,s. ANALYSIS V. (4 cr, §3211, §3411; primarily for math majors, and math majors in the College of Education; prereq 3511)
The calculus of several variables relying heavily on linear algebra. Differentiation and integration of functions of several variables, coordinate systems, Jacobian of a map, implicit function theorem.

3531f,w,s. ANALYSIS VI. (4 cr, §3675; primarily for math majors, and math majors in the College of Education; prereq 3521)
(Continuation of Math 3521) Differential equations, vector analysis.

3581f. FOUNDATIONS OF ARITHMETIC. (4 cr; prereq 3411 or 3211)
Sets, relations, order. Real number system. Continuous functions.

3582w. FOUNDATIONS OF ALGEBRA. (4 cr; prereq 3411 or 3211)
Groups, rings, fields. Applications to number theory and polynomials.

3583s. FOUNDATIONS OF GEOMETRY. (4 cr; prereq 3161)
Axiomatics. Non-Euclidean geometry. Theorems of Desargues and Pappus.

3611-3621. ANALYSIS III-IV. (5 cr per qtr; prereq a grade of C or better in 1621 for 3611... a grade of C or better in 3611 for 3621)
The contents will include a unified treatment of multivariable calculus and linear algebra.

3675f,w,s. INTRODUCTORY MATHEMATICS. (4 cr, §3531; prereq 1231 or 1431 or equiv)
Designed to prepare the sophomore mathematics major for the theoretical courses he will encounter during his junior and senior years.

5151f. ELEMENTARY SET THEORY. (4 cr; prereq 3211 or 3411)
Basic properties of operations on sets, cardinal numbers, simply ordered sets, well-ordered sets, ordinal numbers, axiom of choice, axiomatics.

5152w. ELEMENTARY MATHEMATICAL LOGIC. (4 cr, §5162; prereq 3211 or 3411)
Sets and relations; statement calculus; Boolean algebras; predicate calculus, models, validity and truth; examples of first-order theories as illustrations of the axiomatic method; the completeness theorem, the incompleteness theorem, and meta-mathematics (discussion only).

5154s. AN INTRODUCTION TO RECURSIVE FUNCTION THEORY. (4 cr; prereq 3211 or 3411 or ♯)
Alternative definitions of computability (viz., etc.); primitive, partial, and general recursive functions; Church's thesis; Kleene's normal form theorem and recursive theorem; recursive and recursively enumerable sets; applications to mathematical logic.

5157f-5158w-5159s. MATHEMATICS OF SYMBOL MANIPULATION SYSTEMS. (4 cr per qtr; prereq 1211 or 1411, 3rd-yr standing or ♯)
5157: Finite automata theory; switching circuits, Boolean algebra, and propositional logic. Kleene's theorem on regular sets. Algebraic aspects of finite automata; minimization, decomposition, synthesis. 5158: Computability of numerical functions: proofs for basic result connecting abstract models of programmed digital computers, Turing machines, and general recursive functions. Normal form theorem. Universal machines. Unsolvability of halting problem. 5159: Symbol manipulation systems: formal systems of Herbrand-Godel and Post. Post's normal form theorem. Formal grammars; introduction of Chomsky theory on context-free and other languages and related automata. Transduction of languages by automata.

5162f-5163w-5164s. MATHEMATICAL LOGIC. (4 cr per qtr; prereq 3211 with 3221 or 3411 with 3142 or Phil 5202 or ♯)
Propositional and predicate calculi, models for systems of logic, recursive functions, decision, and completeness problems.

5200. TOPICS IN ALGEBRA. (4 cr [may be repeated for cr with depth approved]; prereq ♯)
Topics vary from quarter to quarter.

5209w,s. THEORY OF NUMBERS. (4 cr; prereq 3211 or 3411)
Elementary properties of integers; prime and composite numbers; Euclid's algorithm; congruences; theories of Fermat and Wilson; primitive roots; indices; Diophantine equations.

5242f,w-5243w,s. LINEAR ALGEBRA WITH APPLICATIONS. (4 cr per qtr, §5283-5284; prereq 3221 or 3142 or 3511)
Systems of linear equations, finite dimensional linear spaces, bases, linear transformations, matrices, determinants, eigenvalues, reduction to canonical forms, quadratic and bilinear forms, applications.

5244s. GROUP THEORY. (4 cr; prereq 3221 or 3142 or 3511)
Permutation groups; groups related to geometrical configuration; invariant subgroups, Jordan-Hölder composition theorem, Sylow groups, Abelian groups, elementary divisors, applications.

5282f,w-5283w,s-5284f,s. FUNDAMENTAL STRUCTURES OF ALGEBRA. (4 cr per qtr, §5244 for 5282; prereq 3675, 3221 or 3142 or 3511)
A theory-oriented course, designed principally for students planning graduate work with mathematics majors. Group theory: normal subgroups, homomorphism, automorphisms, and the theorems of Lagrange, Cayley, and Sylow. Ring theory: rings, ideals, integral domains, Euclidian rings, polynomial rings, field. Linear algebra: abstract approach to vector spaces, linear transformations, and the theory of canonical forms including the Jordan and rational canonical forms.

5300. TOPICS IN GEOMETRY. (4 cr [may be repeated for cr with deptl approval]; prereq ♯)
Topics vary from quarter to quarter.

5341f,w,-5342w,s. INTRODUCTION TO TOPOLOGY. (4 cr per qtr; prereq 3675, 3211 or 3411 or 3521)
Set theory; axiom of choice, Zorn's lemma. Metric spaces: completeness, compactness, continuity. Basic point set topology: countability and separation axioms, Urysohn's lemma, compactness, connectedness, product spaces.

5343. INTRODUCTION TO ALGEBRAIC TOPOLOGY. (4 cr; prereq 5342)
An introduction to algebraic topology. Classification of two-manifolds, fundamental group, homology theory.

5357. PROJECTIVE GEOMETRY. (4 cr; prereq 3211 or 3411)
Geometric properties invariant under projective transformations; theorems of Desargues, Pascal, and Brianchon, and applications. Methods used in some quarters are mainly synthetic, in others mainly analytic.

5359. NON-EUCLIDEAN GEOMETRY. (4 cr; prereq 3211 or 3411)
Foundations of Euclidean geometry. Euclid's fifth postulate and its implications. Hyperbolic plane geometry and trigonometry. Elliptic plane geometry and trigonometry. Consistency of non-Euclidean geometry.

5366f-5367w-5368s. GEOMETRY. (4 cr per qtr; prereq 3211 or 3411 for each qtr)
Selected chapters of geometry, such as convex bodies, projectives geometry, geometry and imagination, elementary algebraic geometry, geometry of transformation groups, axiomatic geometry, geometrical constructions.

5375f. DIFFERENTIAL GEOMETRY. (4 cr; prereq 3231 or 5602)
Plane and space curves. Frenet formulas, elementary theory of surfaces.

5376w-5377s. DIFFERENTIAL GEOMETRY. (4 cr per qtr; prereq 5375 and 1 qtr linear algebra)
Introduction to differential forms. Advanced theory of surfaces, integral geometry, Riemannian geometry.

5404w. VARIATIONAL PROBLEMS. (4 cr; prereq 5602 or 5512 or ‡)
Euler-Lagrange equations, isoperimetric problems, geodesics, Fermat's and Hamilton's principles, methods of Rayleigh-Ritz, eigenvalues and eigenfunctions.

5427-5428. APPLIED MATHEMATICS FOR SOCIAL AND BIOLOGICAL SCIENCES. (4 cr per qtr; not acceptable for math majors [all degrees] as part of their math program; prereq 3211 with 3221 or 3411 with 3142)
Mathematical tools and concepts other than statistics useful in behavioral sciences. Examples and problems from fields concerned. Matrices, functions of several variables, probability, difference equations, learning models, two-person games.

5436-5437. ANALYTICAL DYNAMICS. (4 cr per qtr; prereq 3231 or 5602, 1 qtr linear algebra)
Basic laws and principles. Lagrange's equations. Motion of particles and rigid bodies: e.g., satellites and gyroscopes. Matrix methods for small oscillations. Variational methods, Hamilton's principle, external properties of eigenvalues. Hamilton's equations, transformation theory, separable systems.

5441w. MATHEMATICAL THEORY OF FLUID FLOW. (4 cr; prereq 3231 or 5602, and 5568 or 5572)
General equations of fluid mechanics; thermodynamics. Classical constitutive equations. Specialization to various subfields of fluid mechanics, hydrostatistics, barotropic perfect fluids, gas dynamics, and viscous flow theory. Examples of exact solutions.

5457f-5458w-5459s. METHODS OF APPLIED MATHEMATICS. (4 cr per qtr; prereq 3211 and 3221 or equiv)
Integrated study of analytic tools used in applications of mathematics; emphasis on technique. Real and complex variables, matrices, ordinary and partial differential equations, calculus of variations, asymptotic expansions.

5472f-5473w. INTRODUCTION TO NUMERICAL ANALYSIS. (4 cr per qtr, §CICS 5301, 5302; prereq 3211, 3221, CICS 1100)
5472: Finite differences, interpolation, summation of series, numerical integration, Euler-MacLaurin formula and asymptotic expansions. Numerical solutions of systems of algebraic and transcendental equations. Newton's and Graeffe's method. 5473: Approximation of functions and least squares. Approximate solution of ordinary and partial differential equations. Moulton's, Runge's relaxation and iteration methods. Calculation of eigenvalues of matrices and differential problems, Rayleigh-Ritz method. Integral equations.

5476s. THEORY OF APPROXIMATION IN NUMERICAL ANALYSIS. (4 cr; prereq 5473, 5568 or 5573)
Orthogonal functions, Chebyshev approximations, trigonometric approximations, saturation classes, rational approximations, approximations in several variables, spline interpolation and approximations, use of approximation in computing.

5512. DIFFERENTIAL EQUATIONS. (4 cr, §5523; prereq 3211 and 3066 or 3221 or equiv) First- and second-order equations. Power series solutions. Bessel functions, Legendre polynomials. Introduction to boundary value problems. Mostly a technique course, intended mainly for students whose interests are not theoretical but who wish to learn the relevant mathematical facts and methods.

5514s. INTEGRAL EQUATIONS. (4 cr; prereq 3211 and 3221 or equiv)
Introduction to integral equations; Fredholm formula, Neumann series, Laplace transforms, successive approximations and numerical methods. Relation of integral equations to systems of linear algebraic equations and to differential equations.

5521f,w,s-5522w,s-5523s. INTRODUCTION TO ORDINARY DIFFERENTIAL EQUATIONS. (4 cr per qtr; prereq 3142 or 3221 or 3511, 3211 or 3411 or 3521)
5521: Existence and uniqueness theorems; successive approximations; differential inequalities; linear systems; fundamental matrix solutions; linear systems with constant coefficients; variation of parameters. 5522: Phase plane analysis; Poincare-Bendixson theory; linear and nonlinear oscillations; stability theory; asymptotic behavior of solutions; control theory. 5523: Formal and convergent of power series solutions majorant method; regular and irregular singular points; error estimates perturbation methods.

5541-5542-5543. SPECIAL FUNCTIONS IN MATHEMATICAL ANALYSIS. (4 cr per qtr; prereq 5568 or 5573)
Properties of gamma, hypergeometric, Bessel, and Hermite functions. Applications to mathematical physics. Relationship between symmetry groups and special functions.

5567f,w. FOURIER SERIES AND BOUNDARY VALUE PROBLEMS. (4 cr, §5571; prereq 3211, 3221 or equiv)
Partial differential equations of theoretical physics. Fourier series, proof of convergence, orthogonal systems. Sturm-Liouville systems, solution of boundary value problems by separation of variables, applications.

5568w,s. ELEMENTARY THEORY OF COMPLEX VARIABLES. (4 cr; prereq 5602 or equiv)
Derivative and integral of a function of a complex variable. Cauchy's integral theorem and formula, residues. Application to evaluation of integrals, conformal mapping.

5569s. OPERATIONAL MATHEMATICS. (4 cr; prereq 5568)
Laplace transforms, Fourier transforms, inversion theorems; applications to differential equators.

5571f-5572w-5573s. ELEMENTARY PARTIAL DIFFERENTIAL EQUATIONS. (4 cr per qtr, §5567, 5568; prereq 5603 or 5613)
Partial differential equations of theoretical physics, one-dimensional wave equations, characteristics, classification of second-order equations, heat and Laplace equations, uniqueness, maximum principle, orthogonal systems, Fourier series, separation of variables. Complex numbers, derivatives and integrals of analytic functions, elementary functions and their geometry. Cauchy's integral theorem and formula, Laurent expansions, evaluation of contour integrals by residues. Fourier and Laplace transforms and their inversion, method of residues, applications to ordinary and partial differential equations, applications of heat, wave, and Laplace equations.

5600. TOPICS IN ANALYSIS. (4 cr [may be repeated for cr with deptl approval]; prereq #)
Topics vary from quarter to quarter.

5601f,w-5602w,s-5603s. ADVANCED CALCULUS. (4 cr per qtr; prereq 3211 or 3411)
5601: Differentiation of functions of several variables; vector algebra; curves in three dimensions; directional derivative and gradient inverse transformation and implicit function theorems; change of variables in multiple integrals. 5602: Line and surface integrals; Stokes' theorem; convergence of infinite series; orthogonal functions; uniform convergence; integration and differentiation of series. 5603: Real numbers; continuous functions; limits; properties of continuous functions; differentiation; the Riemann integral; improper integrals.

5606w-5607s. CRITICAL REASONING IN MATHEMATICAL ANALYSIS. (4 cr per qtr, §5612; prereq 3211 or 3411)
Subject matter, based on elementary concepts of mathematical analysis, is chosen mainly to serve the principal aim of the course: development of student understanding of mathematical rigor.

5612f-5613w-5614s. INTRODUCTION TO ANALYSIS. (4 cr per qtr; principally for students planning to take graduate work with a major in mathematics, as preparation for graduate courses in analysis; prereq 3675, 3521 or 3211 with 3221 or 3411 with 3142)
Theory of real numbers; elements of point set theory; limits; differentiation; multivariable analysis.

5615s. LEBESGUE INTEGRAL. (4 cr; prereq 5602 or 5612 or 5607 or ♯)
Basic limit theorems. Comparison with Riemann integral. Lebesgue measure. Absolute continuity.

5625s. DEVELOPMENT OF NUMBER SYSTEMS. (4 cr, §5612; prereq 3211 or 3411)
Systematic construction of real number system by extension from natural numbers via rational numbers to irrational numbers; negative numbers, properties of the system; operations with numbers and laws governing operations.

5644-5645. FOURIER SERIES AND ORTHOGONAL FUNCTIONS. (4 cr per qtr; prereq 5602)
General theory of orthonormal functions developed and applied to Fourier, Legendre, Bessel, Hermite, and other series. Proof of convergence and summability theorems; Fourier integral.

5661-5662. PROBABILITY WITH TECHNOLOGICAL APPLICATIONS. (4 cr per qtr; prereq Stat 5131 and ♯)
Spectral analysis of stationary processes, linear and nonlinear transformations, prediction and smoothing, recurrent events, random walk and diffusion, Markov chains, Poisson processes.

5679. PROBABILITY. (4 cr, §5681; prereq 3211 or 3411 or 3521)
Elementary principles of probability, total and compound probability, expectation, repeated trials. As time permits, topics chosen from Stirling's formula, the probability integral, geometrical probability, probability of causes, Bayes' theorem, errors of observation, principle of least squares.

5681f-5682w-5683s. INTRODUCTION TO PROBABILITY. (4 cr per qtr; prereq 5602 or Stat 5133 or ♯)
Logical development and various applications of probability. Probability spaces, random variables, central limit theorem; Markov chains.

5701f-5702w-5703s. COMBINATORICS. (4 cr per qtr; prereq 3211 or 3411, 3rd-yr standing ...1 qtr linear algebra for 5702)
5701: Basic concepts of combinatorics. Enumeration including binomial counting. Stirling's formula, generating functions, inclusion-exclusion principle, recurrence relations, Polya's theorem, analysis of algorithms. Basic concepts of graph theory and matching theory. Introduction to designs. 5702-5703: Further development of some topics in 5701. Graph theory, optimization, and designs including planar and dual graphs, coloring problems, flows in networks, linear programming, block designs, latin squares, difference sets.

5900. TUTORIAL COURSE IN ADVANCED MATHEMATICS. (Cr ar; prereq ♯)
Qualified students may make arrangements for obtaining content of other graduate courses regularly offered by the department.

5910. PROBLEMS COURSE. (4 cr [may be repeated for cr with deptl approval]; prereq ♯)
Problem-solving techniques in many areas of mathematics. Topics from elementary to advanced levels, adapted to students of varied backgrounds.

5920f,w,s. MATHEMATICS ORIENTATION SEMINAR. (1 cr [may be repeated for maximum of 3 cr]; prereq mathematics major with 3rd-yr standing or ♯)
A nonstructured seminar to facilitate contact between students and faculty. Primarily a discussion course, providing opportunity to examine topics that do not fit into the standard curriculum.

FOR GRADUATE STUDENTS ONLY

8150-8151-8152. AXIOMATIC SET THEORY

8166-8167-8168. RECURSION THEORY

8172-8173-8174. MODEL THEORY

8181-8182-8183. FORMAL LANGUAGES AND AUTOMATA

8190-8191-8192. TOPICS IN LOGIC

8200-8201-8202. GENERAL ALGEBRA

8230-8231-8232. FOUNDATIONS OF ALGEBRA

8236-8237-8238. STRUCTURE OF RINGS AND ALGEBRAS

8245-8246-8247. GROUP THEORY

8260-8261-8262. TOPICS IN NUMBER THEORY AND ALGEBRAIC GEOMETRY

8270-8271-8272. LIE GROUPS AND LIE ALGEBRAS

8290, 8291, 8292. TOPICS IN ALGEBRA

8306-8307-8308. ALGEBRAIC TOPOLOGY

8321-8322-8323. HOMOTOPY THEORY

8330-8331-8332. DIFFERENTIAL TOPOLOGY

8342-8343-8344. TOPOLOGICAL DYNAMICS

8365-8366-8367. RIEMANNIAN GEOMETRY

8374-8375-8376. ALGEBRAIC GEOMETRY

8380-8381-8382. TOPICS IN ADVANCED DIFFERENTIAL GEOMETRY

8406-8407-8408. ADVANCED METHODS OF APPLIED MATHEMATICS

8412-8413-8414. PARTIAL DIFFERENTIAL AND INTEGRAL EQUATIONS OF APPLIED MATHEMATICS

8430-8431-8432. MATHEMATICAL THEORY OF FLUID DYNAMICS

8433. MATHEMATICAL ASPECTS OF BOUNDARY LAYER THEORY

8440. VARIATIONAL METHODS IN BOUNDARY VALUE PROBLEMS

8441. VARIATIONAL METHODS IN EIGENVALUE PROBLEMS

8445. ADVANCED NUMERICAL ANALYSIS OF LINEAR SYSTEMS

8446. ADVANCED NUMERICAL ANALYSIS OF PARTIAL DIFFERENTIAL EQUATIONS

8460-8461-8462. MATHEMATICAL PROBLEMS IN THEORETICAL PHYSICS

8466-8467-8468. JOINT SEMINAR WITH AERONAUTICAL ENGINEERING

8480-8481-8482. SELECTED TOPICS OF CELESTIAL MECHANICS

8500-8501-8502. THEORY OF ORDINARY DIFFERENTIAL EQUATIONS

8516-8517-8518. THEORY OF NONLINEAR OSCILLATIONS

8530-8431. TOPICS IN CONTROL THEORY

8540-8541-8542. TOPICS IN DIFFERENTIAL AND DIFFERENCE EQUATIONS

8550-8551-8552. THEORY OF PARTIAL DIFFERENTIAL EQUATIONS

8560-8561-8562. CALCULUS OF VARIATIONS AND MINIMAL SURFACES

8566-8567-8568. CALCULUS OF VARIATIONS IN THE LARGE

8590-8591-8592. TOPICS IN PARTIAL DIFFERENTIAL EQUATIONS

8600-8601-8602. REAL ANALYSIS

8609-8610. THEORY OF DIFFERENTIATION

8624-8625-8626. GENERALIZED FUNCTONS, DISTRIBUTIONS, AND APPLICATIONS

8630-8631-8632. WIENER AND FEYNMAN INTEGRALS

8640-8641-8642. TOPICS IN REAL ANALYSIS

8650-8651-8652. THEORY OF PROBABILITY

8656-8657-8658. MEASURE AND THEORY AND PROBABILITY

8660-8661-8662. STOCHASTIC PROCESSSES

8666-8667-8668. STOCHASTIC CONTROL THEORY

8672, 8673, 8674. COMBINATIONAL THEORY

8675. INFORMATION THEORY

8680-8681-8682. ERGODIC THEORY

8690-8691-8692. TOPICS IN THE THEORY OF PROBABILITY

8700-8701-8702. COMPLEX ANALYSIS

8706, 8707, 8708. REAL AND COMPLEX ANALYSIS

8720-8721-8722. CONFORMAL MAPPING

8735-8736-8737. RIEMANN SURFACES

8740-8741-8742. THEORY OF QUASICONFORMAL MAPPING

8780-8781-8782. TOPICS IN SEVERAL COMPLEX VARIABLES

8790-8791-8792. TOPICS IN THE THEORY OF ANALYTIC FUNCTIONS

8800-8801-8802. FUNCTIONAL ANALYSIS

8810-8811-8812. TOPOLOGIC GROUPS

8830-8831-8832. BANACH ALGEBRAS AND HARMONIC ANALYSIS

8845-8846-8847. GROUP REPRESENTATIONS

8874-8875-8876. NONLINEAR FUNCTIONAL ANALYSIS AND ITS APPLICATION

8880-8881-8882. TOPICS IN OPERATOR THEORY

8990-8991-8992. READING AND RESEARCH

Mechanical Engineering (ME)

1001. INTRODUCTION TO MECHANICAL ENGINEERING. (1 cr; S-N only; 1 lect hr per wk)
An introduction to mechanical engineering presented by practicing engineers and members of the faculty. Topics include the mechanical engineering curriculum, the elective program, the mechanical engineering profession, and related areas of research.

3201. MECHANICAL ENGINEERING SYSTEMS ANALYSIS. (4 cr; prereq Math 3221 or equiv; 3 lect and 1 rec/lab hrs per wk)
Modeling and analytic description of mechanical systems. Properties of linear models with emphasis on automatic computation solution.

3203. ANALYSIS OF MECHANISM SYSTEMS. (4 cr; prereq AEM 3036 or equiv; 3 lect and 1 rec/lab hrs per wk)
Diagnostics of the performance of mechanism systems involving linkage, hydraulic, pneumatic, and electro-mechanical components. Energy balance techniques used to describe energy flow through machine systems.

3205. ENGINEERING SYSTEMS DESIGN. (4 cr; prereq 3201, 3203; 3 lect and 2 lab hrs per wk)
Application of fundamental concepts to the design of typical mechanical components. Engineering approach to the analysis and synthesis of machines and systems. Specification of materials in engineering design. Optimum design criteria.

3301. THERMODYNAMICS. (4 cr; prereq Chem 1014 or Phys 1281, Math 3221 or equiv; 4 lect hrs per wk)
Properties, equations of state, processes, and cycles for various thermodynamic systems. Development of first and second laws of thermodynamics, correlating heat, work, and mass transfer. Equilibrium, irreversibility and mixtures.

3303. APPLIED THERMODYNAMICS. (4 cr, §3305; prereq 3301 or equiv; 4 lect hrs per wk)
Application of laws of thermodynamics to chemically reacting systems and engineering systems. Analysis of vapor cycles, gas engine cycles, propulsion systems, refrigeration, and air-water vapor mixtures.

3305. PROPULSION THERMODYNAMICS. (4 cr, §3303; prereq 3301, AEM 5200 or equiv; 4 lect hrs per wk)
Principles of thrust production, momentum, energy, and mass flow functions; chemical equilibrium, combustion, flame temperature. Thermodynamics of turbojet, turbofan, turboprop, rocket, and engine units.

3701-3702. BASIC MEASUREMENTS LABORATORY I AND II. (2 cr per qtr; prereq ME 3301, or ¶3301 for 3701...3701 for 3702; 1 lect and 3 lab hrs per wk)
Treatment of experimental data, analysis and study of experimental systems via the computer. Static and dynamic characteristics of measurement systems. Fundamental principles of measurement and calibration. Measurement of temperature, pressure, vacuum, humidity, density, viscosity, heating values, speed, power, force, stress-strain, and radioactivity.

3703. ADVANCED MECHANICAL ENGINEERING LABORATORY. (2 cr [may be repeated for cr]; prereq 3702 or equiv; 4-hr lect-lab combination per wk)
Systems measurement and evaluation involving various areas of study in mechanical engineering. Each quarter involves 2- to 5-week laboratory modules as selected by the student.

3740. INDUSTRIAL ASSIGNMENT. (2 cr per qtr [may be repeated for cr]; prereq regis in intern program)
Engineering intern curriculum industry laboratory assignment (work quarter). Grades based on formal report written by the student covering his work during industrial assignment.

3900. INTRODUCTION TO ENGINEERING STATISTICS. (4 cr; prereq Math 1231 or equiv; 3 lect and 1 rec hrs per wk)
Elements of probability, descriptive statistics, binomial and Poisson distributions; normal distribution, estimation, hypothesis testing, regression analysis, and analysis of variance.

5190. ADVANCED ENGINEERING PROBLEMS. (2-4 cr; open to upper division students; prereq approved deptl permission form)
Work pertaining to special investigations in various fields of mechanical engineering and related areas including independent study project.

5203. ADVANCED ANALYSIS AND SYNTHESIS OF MECHANISM SYSTEMS. (3-4 cr [1-cr term paper option]; prereq 3203 and computer programming; 3 lect hrs per wk)
Kinematic and dynamic analysis of mechanism systems, gears, and cams. Synthesis of mechanism systems, function generation, coupler curves, and computerized design of mechanism systems.

5205. CREATIVITY IN ENGINEERING DESIGN. (3-4 cr [1-cr term paper option]; prereq completion of basic core of ME program or equiv recommended; 3 lect hrs per wk)
Study of the role of creative action at various stages in the morphology of the design process. Creative decision making in developing design criteria, alternative solutions, and their evaluation.

5207. EXPERIMENTAL STRESS ANALYSIS. (4 cr; prereq AEM 3016; 3 lect and 3 lab hrs per wk)
Experimental application and theoretical evaluation of methods of stress analysis. Strain gages, surface coatings, photoelasticity techniques. Design of transducing systems utilizing strain.

5209. FRICTION AND LUBRICATION. (3-4 cr [1-cr term paper option]; prereq CE 3400 or equiv; 3 lect hrs per wk)
Solid friction mechanism and boundary lubrication. Hydrodynamic and hydrostatic lubrication theory applied to bearing design. Introduction to gas bearings.

5244. VIBRATION ENGINEERING. (4 cr; prereq 3201 or equiv; 4 lect hrs per wk)
Applications of the theory of vibration to the design and optimization of isolators, detuning mechanism, viscoelastic suspensions and structures.

5254. DESIGN MORPHOLOGY WITH APPLICATIONS. (4 cr; prereq completion of 3rd-yr engineering courses recommended; 2 lect and 2 lab sessions per wk)
Detailed study of design problem formulation and the structure of the open-ended solution process based on design morphology. Case studies and student projects as instructional vehicles.

5255. ENGINEERING DESIGN PROJECT. (4 cr [may be repeated for cr]; prereq 5254 or equiv recommended; 1 lect and 2 lab sessions per wk)
Participation in the solution of systems design problems which have developed criteria, order-of-magnitude evaluation of alternatives, and the generation of the preliminary design.

5260. ENGINEERING MATERIALS AND PROCESSING. (4 cr; prereq Phys 1291, Chem 1004 and 1st-yr calculus; 3 lect and 1 rec hrs per wk)
Introduction to materials and processing, including physical and metallurgical properties, consolidation, etc. Materials processing, including machining, welding, and deformation processes.

5262. MATERIALS WORKING AND FABRICATION PROCESSES. (4 cr; prereq 5260 or equiv recommended; 3 lect and 1 rec hrs per wk)
Theory and application of joining techniques, welding, brazing, and adhesive bonding. Metal forming operations, rolling, swaging, drawing, etc. Inspection and test methods to control and evaluate fabrication processes including X-ray, magnetic, metallographic, and chemical methods.

5264. MATERIALS CONSOLIDATION PROCESSES. (4 cr; prereq 5260 or equiv recommended; 3 lect and 1 rec hrs per wk)
Theory and practice of materials consolidation including casting and powder metal processes. Composite materials techniques.

5266. MATERIALS FINISHING PROCESSES. (4 cr; prereq 5260 or equiv; 3 lect and 1 rec hrs per wk)
Theory and practice of metal removal and finishing including mechanical, chemical, and electrolytical methods. Techniques of surface preparation, plating, abrasive and chemical cleansing, coatings, and films.

5268. PROPERTIES AND FABRICATION OF PLASTICS. (4 cr; prereq 5260 or equiv; 3 lect and 1 lab/rec hrs per wk)
Materials, equipment, and processes for fabrication of plastics. Principles of products and tool design. Hydraulic and temperature circuit control for equipment.

5270. MATERIALS: DESIGN REQUIREMENTS. (4 cr; prereq 5260 or equiv recommended; 3 lect and 1 rec hrs per wk)
Fundamental properties of engineering materials including fabrication, treating, physical and corrosion properties. Failure mechanism, cost and value analysis as related to materials selection and specification.

5283. INDUSTRIAL INSTRUMENTATION AND AUTOMATIC CONTROL. (4 cr; prereq 3201 or equiv; 3 lect and 3 lab hrs per wk)
Theory and operation of instruments and automatic control. Industrial controls including fluidic controls. On-off, proportional, floating, and rate response in control systems.

5284. CONTROL SYSTEMS. (4 cr; prereq 3201 or equiv; 4 lect hrs per wk)
Basic theory of linear feedback control systems. Transfer function representation of solid body, fluid, pneumatic, and electro-mechanical components. On-off, proportional, floating, and rate response in control systems, including industrial instrumentation.

5342. HEAT TRANSFER. (4 cr; prereq Math 3221, CE 3400 or equiv; 4 lect hrs per wk)
Steady and unsteady conduction of heat. Convection heat transfer in boundary layer and duct flows; forced and free convection; condensation and boiling; heat exchangers. Heat transfer by thermal radiation; radiative properties of black bodies and real surfaces.

5344. THERMODYNAMICS OF FLUID FLOW. (4 cr; prereq CE 3400, ME 3301 or equiv; 4 lect hrs per wk)
Compressible flow of gases in engineering systems such as nozzles, ducts, combustion chambers, ramjets, pipelines, etc. Isentropic flow in variable area passages. Shock waves. Flow with wall friction, heat transfer, and mass transfer.

5380. REACTOR HEAT TRANSFER. (3 cr; prereq 5342 or equiv; 3 rec hrs per wk)
Heat conduction with internal heat generation, thermal stresses, liquid metal heat transfer, forced convection in noncircular ducts, boiling, and two-phase flow.

5442. VAPOR CYCLE POWER SYSTEMS. (3-5 cr [1-2 cr term paper option]; prereq 3303 or equiv; 3 lect hrs per wk)
Vapor cycle analysis, regeneration, reheat, compound cycle modifications, combined gas turbine-vapor cycle systems and binary systems. Combustion problems; solar, nuclear, and unusual energy sources for space power systems.

5443. TURBOMACHINERY. (3-5 cr [1-2 cr term paper option]; prereq 3301 or equiv; 3 lect hrs per wk)
Theoretical analysis of energy transfer between fluid and rotor, principles of axial, mixed, and radial flow compressors and turbines. Applications to power plants, fluid transmissions, and propulsion systems.

5446. AN INTRODUCTION TO COMBUSTION. (4 cr; prereq 5342 or equiv; 4 lect hrs per wk)
Flame propagation, quenching, and ignition in a gaseous mixture; combustion of solid and liquid particles, and gaseous jets. Applications to selected propulsion systems.

5455. ROCKET PROPULSION. (3-5 cr [1-2 term paper option]; prereq 3303 or equiv; 3 lect hrs per wk)
Mode of operation and performance limitations of chemical rockets with liquid, solid, and free radical propellants, nuclear and solar rockets with thermal and electromagnetic propellant acceleration.

5460. INTERNAL COMBUSTION ENGINES. (4 cr; prereq 3301 or equiv; 4 lect hrs per wk)
Principles of power production, fuel consumption, and emissions of gasoline and Diesel engines; fuel-air cycle analysis, combustion flames, knock phenomena, air flow and volumetric efficiency, mixture requirements, ignition requirements and performance.

5461. ADVANCED INTERNAL COMBUSTION ENGINES. (3-5 cr [1-2 cr term paper option]; prereq 5460 or equiv; 3 lect hrs per wk)
Hydrocarbon fuels, octane and cetane ratings, additives and deposits; lubrication systems, lubricants, additives for control of friction; air and liquid coolings; engine design problems.

5462. GAS TURBINES. (4 cr; prereq 3301 or equiv; 4 lect hrs per wk)
Gas turbine cycles, regeneration, reheat, and intercooling. Axial and radial flow compressors and turbines; burner types and combustion efficiency; emissions and noise. Matching of compressor and turbine. Turbojet, fanjet and turboprop engine performance.

5480. BIOLOGICAL FLUID FLOW. (3-4 cr [1-1 cr term paper option]; prereq CE 3400 or equiv; 3 lect hrs per wk)
Introduction to rheology and fluid dynamics of biological fluids. Topics include blood flow, biological pumping, self-propelled particles, unusual viscoelastic behavior of biological fluids, and other fluid motions.

5603. THERMAL ENVIRONMENTAL ENGINEERING. (4 cr; prereq 3303, 5342 or equiv; 4 lect hrs per wk)
Thermodynamic properties of moist air; h-W diagram for moist air; solar radiation; heat and water vapor transmission in structures; effects of thermal environments upon people, processes, and materials; thermal loads, thermal environmental control systems.

5605. REFRIGERATION. (4 cr; prereq 3303; 4 lect hrs per wk)
Mechanical vapor compression systems; absorption systems; thermoelectric cooling; gaseous air cycle; steam-jet refrigeration. Liquefaction of air, hydrogen, and helium; production of oxygen and nitrogen by separation of air.

5607. INDUSTRIAL VENTILATION AND CONTAMINANT CONTROL. (4 cr; prereq CE 3400, ME 3303 or equiv; 4 lect hrs per wk)
Contaminants, dispersion mechanisms, transport, fans, hoods, gas cleaners, behavior of jets and sinks, closed and open systems, applications to industrial processing and emission control.

5612. ENVIRONMENTAL ENGINEERING. (4 cr; prereq upper division; 4 lect hrs per wk)
Basic principles of engineering assessment and control of emissions to air and water; noise measurement and control; control, handling, and disposal of solid waste.

5613. PRINCIPLES OF PARTICLE TECHNOLOGY. (4 cr; prereq 3303 recommended; 4 lect hrs per wk)
Definition, theory, and measurement of particle properties, particle statistics, fluid dynamics, optical, electrical, and thermal behavior of particles.

5614. PRINCIPLES OF PARTICLE TECHNOLOGY. (4 cr; prereq 5613; 4 lect hrs per wk)
Gas cleaning, particle transport, comminution, classification, surface properties, packed beds, powder behavior, and miscellaneous topics.

FOR GRADUATE STUDENTS ONLY

8190. MECHANICAL ENGINEERING GRADUATE SEMINAR

8210. ADVANCED VIBRATION ENGINEERING

8211-8212-8213. APPLIED DYNAMICS

8243. PHOTOELASTICITY

8280-8281-8282. FEEDBACK CONTROL SYSTEMS

8310. ADVANCED THERMODYNAMICS

8311. STATISTICAL AND NONEQUILIBRIUM THERMODYNAMICS

8326. BOILING HEAT TRANSFER AND MULTIPHASE FLOW

8330. CONDUCTION

8331. CONVECTION

8332. RADIATION

8333. ADVANCED THEORY OF HEAT TRANSFER

8350. ADVANCED FLUID THERMODYNAMICS

8360-8361-8362. THERMODYNAMICS OF HIGH TEMPERATURE GASES

8370-8371-8372. MAGNETOHYDRODYNAMICS

8442. ADVANCED POWER PLANTS

8443. THERMOCHEMICAL ANALYSIS OF POWER SYSTEMS

8444-8445. THERMODYNAMICS AND CHEMICAL KINETICS OF COMBUSTION

8446. ENERGY TRANSPORT IN CHEMICALLY REACTING GASES

8447. MASS TRANSFER IN CHEMICALLY REACTING GASES

8448. ATOMIZATION, VAPORIZATION, AND MIXING

8450. DYNAMICS OF HIGH-SPEED ENGINES

8453. ADVANCED GAS TURBINES AND JET PROPULSION

8455. ADVANCED ROCKET PROPULSION

8485-8486-8487. BIOMEDICAL ENGINEERING SEMINAR

8600-8601. PSYCHROMETRICS AND AIR CONDITIONING

8603. THEORETICAL REFRIGERATION

8770-8771-8772. MECHANICAL ENGINEERING RESEARCH

8773-8774-8775. GRADUATE SEMINAR

Metallurgy/Materials Science (MatS)

1002. INTRODUCTION TO MATERIALS. (2 cr)
The field of materials science, origins of microstructure, structure-sensitive properties. Career orientation.

3090, 3091, 3092. INDUSTRIAL EMPLOYMENT. (1-2 cr [depending upon duration of employment])
Employment with industrial firms having metallurgical or materials engineering activities. Report covering work required.

3400. MECHANICAL PROPERTIES OF MATERIALS. (4 cr; prereq 2nd yr IT students)
Introduction to structure and properties of metals, alloys, and polymers; heat treatment; alloy selection and metal processing; specifically for mechanical, aero, civil, and other engineering students outside of chemical engineering and materials science.

3501. QUANTITATIVE METALLOGRAPHY AND ELECTRON MICROSCOPY. (3 cr; 1 lect, 1 rec, 2 lab hrs per wk)
Microstructure of materials, temperature measurement and control, equilibrium diagrams, quantitative metallography, electron microscopy.

3502. PHYSICAL METALLURGY LABORATORY. (3 cr; 1 lect, 4 lab hrs per wk)
Solidification of metals and alloys, transformations in solids, hardenability, surface treatment of metals, metallurgical problems.

3521. X-RAY METALLOGRAPHY. (3 cr; 1 lect, 1 rec, 2 lab hrs per wk)
Physics of X-ray diffraction, powder patterns, crystal orientation, microradiography, application to metallurgy and materials science, solvus determination, phase equilibria, structure of cold worked metals.

5011-5012-5013. INTRODUCTION TO SCIENCE OF MATERIALS. (4 cr; prereq 3rd yr IT students)
Introduction to relation between atomic and electronic structure of metals, semiconductors, insulators, and polymers and important properties of materials.

5101. THERMODYNAMICS AND MATERIALS STATES. (4 cr; 3 lect and 2 rec hrs per wk) Staff
(Same as ChEn 5201) Principles of thermodynamics applied to closed and open systems and to equilibrium states of homogeneous and heterogeneous substances, gases, liquids, and solids.

5102. THERMODYNAMICS AND KINETICS OF THE SOLID STATE. (4 cr; prereq course in chemical thermodynamics)
Theory of solids, heterogeneous equilibria, free energy-composition diagrams, diffusion and reaction kinetics.

5111. MATHEMATICAL METHODS IN CHEMICAL ENGINEERING AND MATERIALS SCIENCE. (2 cr; 2 lect and 1 rec hrs per wk)
(Same as ChEn 5001) Computer programming with applications to chemical, physical, and engineering problems.

5301. CONTROL OF MECHANICAL PROPERTIES IN METALS AND ALLOYS. (4 cr; 3 lect and 2 lab hrs per wk)
Mechanical properties of metals and alloys are discussed in terms of dislocation behavior, creep, fatigue, fracture toughness. Attention to control of mechanical properties through manipulation of microstructure by metal processing.

5303. ANALYSIS OF METALLURGICAL PROBLEMS. (4 cr; 2 lect and 4 lab hrs per wk)
Specialized metallurgical subjects such as embrittlement of steels, residual stresses, wear, and fatigue in metals with primary emphasis on failure analysis.

5401-5402-5403. PRINCIPLES OF PHYSICAL METALLURGY. (4 cr; prereq 5012 or ‡)
Fundamentals of solidification, transformations: strength, deformation and fracture of solids, casting, hardenability, heat treatment of alloys; surface treatment, joining, working of metals.

5450. CORROSION OF METALS. (3 cr; prereq background in materials science and thermodynamics desirable; 3 lect hrs per wk)
Electrochemical theory, mechanisms of corrosion, theories of passivity, influence of environmental factors on corrosion. High temperature oxidation, corrosion control, organic coatings, alloying, inhibitors.

5481, 5482, 5483. SPECIAL PROBLEMS IN PHYSICAL METALLURGY AND MATERIALS SCIENCE. (Cr and hrs ar; prereq sr standing)
Library or laboratory studies of scientific or engineering problems in physical metallurgy and materials science.

5610. POLYMERIC MATERIALS. (4 cr; prereq Chem 5501 or ‡; 3 lect and 3 lab hrs per wk)
Introduction to polymerization and structure of synthetic and biopolymers. Effect of structure on crystallinity, physical properties, and viscoelastic behavior. Fabrication processes, applications of polymers, and their environmental degradation.

5620. POLYMER PROCESSING. (4 cr; prereq 5610)
Theory and practice of processing polymer melts and solids.

FOR GRADUATE STUDENTS ONLY

8110. THERMODYNAMIC PROPERTIES OF SOLIDS: CLASSICAL AND STATISTICAL MECHANICS APPLIED TO STUDY OF THE PROPERTIES OF SOLIDS

8111. TRANSPORT PROCESSES IN SOLIDS

8112. SOLID STATE REACTIONS

8210. CRYSTALLINE PROPERTIES OF METALS

8211. MODERN THEORY OF METALS AND ALLOYS

8212. IMPERFECTIONS IN METALS

8213, 8214. STRUCTURE AND COHESION OF METALS AND SEMICONDUCTORS

8220. TOPICS IN LOW TEMPERATURE METAL PHYSICS

8301. ELECTRON INTERACTION WITH SOLIDS

8310-8311. THEORIES OF MECHANICAL BEHAVIOR OF SOLIDS

8320. HIGH TEMPERATURE PROPERTIES OF MATERIALS

8401, 8402. TRANSFORMATIONS IN MICROSTRUCTURE

8470, 8471, 8472. SEMINAR: MATERIALS SCIENCE AND ENGINEERING

8480, 8481, 8482. SELECTED TOPICS IN MATERIALS SCIENCE AND ENGINEERING

8520. ELECTRON DIFFRACTION AND ELECTRON MICROSCOPY

8522. ADVANCED X-RAY DIFFRACTION OF METALS

Mineral Engineering (MinE)

5530. FLUID FLOW THROUGH POROUS SOLIDS I. (4 cr; prereq 5613 or ♯)
Petrophysics of porous rocks and aquifers; porosity, permeability, mineral surface areas; linear, radial, and spherical flow for various types of fluids; units. Laboratory experiments.

5532. FLUID FLOW THROUGH POROUS SOLIDS II. (4 cr; prereq 5530 or ♯)
Fluid flow possibilities. Darcy's generalized equations; vertical flow; units. Kozeny equations derived; fracture and channel flow; electrical, acoustical, and radioactivity properties of rocks pertaining to porosity and connate water of rocks treated. Oil reservoirs, material balance and volumetric petroleum reserves estimations; rock compressibility effects; fractional flow equations.

5534. EARTH FLUIDS AND FLUID FLOW. (4 cr; prereq 3rd yr or ♯)
Sedimentary rocks and earth fluids characteristics. Fluid flow through porous rocks. Basic principles of oil reservoir engineering; energies and mechanisms of petroleum production.

5611. MINERAL RESOURCES I: INTRODUCTORY COURSE. (4 cr; prereq Geo 1111 desirable or ♯)
Mineral distribution and demand; nongeologic ore determinants, unit operations of exploration, development, and production of mining and petroleum deposits; environmental control; valuation principles.

5612. MINERAL RESOURCES II: EXPLORATION DEVELOPMENT AND EXPLOITATION OF MINERAL PROPERTY. (4 cr; prereq 5611 or ♯)
Integrated exploration, development, and production systems for underground mineral properties. Essential criteria for design and selection of mining methods. Unit operations: drilling, blasting, supporting, loading, and hauling.

5613. MINERAL RESOURCES II: EXAMINATION AND VALUATION OF MINERAL PROPERTY. (4 cr; prereq Geo 1111 and MinE 5612 or 5630 desirable or ♯)
Geologic factors and mineral laws, sampling and reserve estimates. Analysis of costs and profitability. Taxation, depreciation, and depletion. Present worth and rate-of-return computations; financing methods.

5619. ENGINEERING FIELD STUDY. (3 cr; prereq sr or grad mineral or geological engr or ‡; 2 wks during summer)
Mining and petroleum operations; mine and petroleum metallurgical plants; research engineering offices in selected regions.

5630. SURFACE MINING ENGINEERING. (4 cr; prereq Geo 1111 and MinE 5611 or ‡)
Unit operations of drilling, blasting, loading, hauling, and transporting of surface rocks and soils. Equipment productivity, selection, and cost estimating. Design of open pits and quarries. Economics, environment, and organization.

5640. MINERAL ECONOMICS. (3 cr; prereq 5613 or ‡)
Distribution, demand, and conservation of strategic supplies. Marketing and prices. State and national policies effecting development. Analysis of mineral data.

5650-5652. MINERAL ENGINEERING DESIGN I, II. (4 cr each; prereq sr or grad student in mineral engineering; 10 design hrs per wk)
Systems design for the exploration, development, and exploitation of a mineral property. Integration of concepts from geology and geophysics, rock mechanics, mine and petroleum plant engineering, and mineral economics and valuation principles to a specific problem chosen by student. Preparation of report.

5660. SPECIAL MINERAL ENGINEERING PROBLEMS. (Cr and hrs ar; prereq 5612)
Literature survey or research work on mining problems.

5700. SYSTEMS ANALYSIS FOR MINERAL ENGINEERS. (4 cr; prereq ‡)
Applications of operations research techniques to optimization in mining; probabilistic and deterministic simulation as applied to mining and mill systems.

5710. ENVIRONMENTAL ENGINEERING FOR MINERAL ENGINEERS. (4 cr; prereq ‡)
Environmental and ecological problems of underground and surface mining, processing, and smelting. Types of mining hazards, safety and health considerations in design of mine equipment and systems. Pollution aspects of mineral extraction and processing. Land reclamation and mining.

5800. INTRODUCTION TO MINERAL AND METAL EXTRACTION. (4 cr; prereq inorganic chemistry)
Unit operations in processing a mineral product to a desirable concentrate form. Unit processes in treating the concentrate to the required metallic state. Economic and environmental considerations in the coordinated sequence of events.

5810. PRINCIPLES OF MINERAL PROCESSING. (4 cr; prereq 3rd yr IT)
Application of physical and chemical principles to solid material processing problems. Screening, size reduction and size classification, solid transport and storage, mixing and dispersing, flocculation and dispersion, size and gravity classification, filtration and drying, flotation, electrical separation and electrostatic precipitation, magnetic separation, hydrometallurgy, miscellaneous processes.

5816. HYDROMETALLURGY I. (3 cr; prereq ‡)
Application of physicochemical principles to the leaching of ores and concentrates, to purification of leach liquors, and recovery of metals from solutions.

5818. HYDROMETALLURGY II. (4 cr; prereq ‡)
Application of physicochemical principles to the leaching of metals, ores, and concentrates; to purification of leach solutions; and to the recovery of metals. Integration of operations and processes on a plant basis.

5820. PRINCIPLES OF METALS EXTRACTION I. (4 cr; prereq 8 cr inorganic chemistry)
Materials and heat balances in metallurgical processes. Chemical equilibrium and rates of reaction. Combustion of fuels and heat utilization. Phases in pyrometallurgical systems.

5825. PRINCIPLES OF METALS EXTRACTION II. (4 cr; prereq 5820 or ‡)
Fluid flow and heat transfer concepts in metallurgical systems. Theory and correlation to industrial practice. Applications to temperature measurements, thermal insulation, and the heating and cooling of solid bodies.

5830. MICROSCOPY FOR MINERAL ENGINEERS. (3 cr; prereq ‡)
Petrographic and metallographic microscopic identification of minerals and ores. Elementary optics and the optical characteristics of nonopaque and opaque minerals. Application of microscopy to the mineralogical and textural factors which exercise fundamental control over beneficiation processes.

5910. METALLURGICAL UNIT PROCESSES. (4 cr; prereq 5825 or ‡)
Unit processes of chemical metallurgy are covered in chronological order; roasting, agglomeration, smelting, converting, refining, vaporization, and electrolytic methods.

5940. SPECIAL PROBLEMS IN EXTRACTIVE METALLURGICAL ENGINEERING. (Cr and hrs ar; prereq sr)
Laboratory investigation of problems in extractive metallurgy.

FOR GRADUATE STUDENTS ONLY

8330. ADVANCED CONCEPTS IN DRILLING OF ROCKS

8470-8471-8472. MINING RESEARCH PROBLEMS I, II, III

8601-8602, 8603. SEMINAR: MINERAL ENGINEERING

8620. ADVANCED ENGINEERING DESIGN

8632. GRAVITY FLOW OF FRAGMENTED MATERIALS

8640. ADVANCED MINERAL ECONOMICS

8724. MINE ENVIRONMENT ENGINEERING

8730-8732. OPERATIONS ANALYSIS IN MINERAL ENGINEERING I, II

8818. HYDROMETALLURGY

8830. ELECTRIC AND MAGNETIC SEPARATION OF MINERALS

8832-8834-8836. TECHNIQUES OF MINERAL PROCESSING RESEARCH I, II, III

8838-8839. OPTIMIZATION AND CONTROL TECHNIQUES IN MINERAL PROCESSING I, II

8840. FLOTATION THEORY

8842. SURFACE CHEMISTRY OF FLOTATION

8921-8922-8923. RESEARCH IN EXTRACTIVE METALLURGICAL ENGINEERING

8925-8926-8927. SEMINAR: EXTRACTIVE METALLURGICAL ENGINEERING

8930-8932-8934. PHYSICAL CHEMISTRY OF HIGH TEMPERATURE METALLURGICAL REACTIONS I, II, III

Physics (Phys)

1014-1024. INTRODUCTORY PHYSICS: CONCEPTS IN PHYSICS. (4-4 cr, §other introductory physics courses; cannot be used as prereq for physics or biological science majors; prereq HS algebra and plane geometry; may be taken with or without the accompanying lab, 1015-1025; 3 lect hrs and 1 prob hr per wk)
Demonstration lectures on principles of physics. Includes topics in mechanics, electricity and magnetism, waves, and 20th-century physics (relativity and quantum theory). Primarily for students interested in the ideas of 20th-century physics.

1015-1025. INTRODUCTORY PHYSICS LABORATORY. (1 cr per qtr; S-N only; prereq 1014 or ¶1014 for 1015, 1024 or ¶1024 for 1025; 2 lab hrs per wk)
Laboratory experiments offered in conjunction with Phys 1014-1024.

1031-1032. INTRODUCTORY PHYSICS: MEASUREMENT AND APPLICATIONS. (5-5 cr, §other introductory physics courses; prereq high school algebra and plane geometry; 4 class hrs and one 2-hr lab or prob session per wk)
Demonstration lectures, problem sessions, and laboratory exercises on topics in physics. Application of physics will be emphasized. Topics include mechanics, random processes, gases and fluids, electric circuits, feedback and control, waves, light, optical instruments, atoms and spectra, nuclei, and radioactivity. Primarily for students interested in those topics useful in various technical areas.

1041-1042. INTRODUCTORY PHYSICS: PHYSICS AND MANKIND. (5 cr per qtr, §other introductory physics courses; prereq high school algebra and plane geometry; does not satisfy prereq for any other courses; 4 lect and 1 discussion hrs per wk)
Important concepts and discoveries in physics—their relationship to the humanities, other sciences, and to society.

1051-1052. INTRODUCTORY PHYSICS: ENVIRONMENTAL PROBLEMS. (4 cr per qtr, §other introductory physics courses; prereq high school algebra and plane geometry; 3 lect and 1 discussion hrs per wk)
Basic physics for students interested in understanding environmental problems. Energy; entropy; mechanics; optics; applications.

1061. PHYSICS OF HUMAN MOTION. (4 cr; prereq 1 yr high school algebra; 3 lect discussions per wk and one 2-hr gym lab every 2 wks)
Basic concepts of classical mechanics applied to motion of human bodies in various forms of work, athletics, and dance. Hydrodynamics applied to swimming. Physics of muscles. Five gymnasium labs.

1104-1105-1106. GENERAL PHYSICS. (5-5-5 cr; primarily for premedical students; prereq Math 1142, high school trigonometry or Math 1008 for 1104, 1104 for 1105, 1105 for 1106; 4 lect, 1 quiz, 2 lab hrs per wk)
1104: Mechanics. 1105: Heat and electricity. 1106: Sound and light. Laboratory work is an integral part of course.

1121-1122. PHYSICS FOR ARCHITECTS. (5 cr per qtr; prereq Math 1211; 4 lect and 1 prob hrs per wk and occasional labs)
Principles of physics useful to pre-architecture students. Mechanics, heat, electric circuits, light, properties of materials.

1271-1281-1291. GENERAL PHYSICS. (4 cr per qtr; prereq Math 1221 or ¶, 1321 or ¶, or 1621 or ¶ or equiv for 1271...Math 1231 or ¶, 1331 or ¶, or 1621 or ¶ or equiv for 1281; may be taken with or without lab 1275-1285-1295; 3 lect, 1 prob, and 1 quiz hrs per wk)
Calculus-level general physics course. **1271:** Mechanics. **1281:** Heat, electricity. **1291:** Magnetism, optics.

1275-1285-1295. GENERAL PHYSICS LABORATORY. (1 cr per qtr; S-N only; prereq 1271-1281-1291 or ¶; 2 lab hrs per wk)
Laboratory exercises in general physics.

3011. OSCILLATIONS. (4 cr; prereq 1291, Math 3211 or equiv; 3 lect and 1 prob sessions per wk)
Physical and mathematical study of the harmonic oscillator. Transient behavior; resonance; impedance; mechanical and electrical examples; coupled systems; traveling and standing waves in one dimension; Fourier series.

3012. WAVES AND OPTICS. (4 cr; prereq 3011; 3 lect and 1 prob sessions per wk)
Waves in two and three dimensions. Standing waves; interference; diffraction; polarization; radiation. Examples emphasizing electromagnetic radiation.

3015. LABORATORY IN OSCILLATIONS AND WAVES. (1 cr; prereq 3011, 3012 or ¶3012; 3 lab hrs per wk)
Laboratory exercises in oscillations and waves.

3501. MODERN PHYSICS. (4 cr, §3511-3512-3513; prereq 1291 or 1106; 3 lect and 1 prob hrs per wk)
Descriptive course in modern physics; quantum mechanics, hydrogen atom, multielectron atoms, molecular structure, quantum statistics, thermal radiation, solid state physics, nuclear physics.

3505. PHYSICS LABORATORY. (1 cr; prereq 3501 or ¶; 2 lab hrs per wk)
Laboratory experiments in modern physics.

3511-3512-3513. MODERN PHYSICS. (4-4-4 cr; prereq 1291 or 1106, Math 1231 for 3511... Math 3221 or Math 3066 or equiv for 3512; 3 lect and 1 prob session per wk)
Introductory course in special relativity, quantum mechanics, atomic, molecular, solid state, and nuclear physics. Emphasis on experimental phenomena.

3515. PHYSICS LABORATORY. (1 cr; prereq 3513 or ¶; 3 lab hrs per wk)
Laboratory experiments in atomic, solid state, and nuclear physics.

3801. INTRODUCTION TO THE PHYSICS OF PHOTOGRAPHY. (5 cr; prereq high school algebra, some photographic experience; 3 lect, 1 discussion, and 2 lab hrs per wk)
Principles of optics and electricity applied to the photographic processes. Image formation; intensity and color of illumination; exposure of photographic materials. Understanding technical literature as applied to pictorial photography (or tone reproduction); some discussion of line reproduction.

3900. INDUSTRIAL SUMMER EMPLOYMENT. (1 cr; prereq 3 yrs academic work plus deptl approval during previous spring qtr)
Ten weeks of employment (contracted by the student) in a professional or semiprofessional capacity doing work in the field of physics. A written report approved by the employer and the department.

3970. DIRECTED STUDIES. (1-5 cr; prereq ♯, △)
Independent, directed study in physics, in areas arranged by the student and a faculty member.

5011-5012-5013.° MECHANICS, ELECTRICITY, AND MAGNETISM. (4-4-4 cr, §5021-5022, §5023-5024; prereq 3011, Math 3211, 3221 or equiv; 4 lect hrs per wk)
Theoretical mechanics and electricity and magnetism.

5021-5022.° INTRODUCTION TO ANALYTIC MECHANICS. (4 cr per qtr, §5011-5012-5013; prereq 3011, Math 3231 or equiv; 3 lect and 1 prob hrs per wk)
Analytic course in Newtonian mechanics. Vectors and vector operators; angular momentum; central force problem; system of particles; tensors; rigid bodies; moving coordinate systems; continuous media; Lagrange's equations. Mathematics beyond the prerequisites developed as required.

5023-5024.° INTRODUCTION TO ELECTRIC AND MAGNETIC FIELDS. (4-4 cr, §5011-5012-5013; prereq 3011, Math 3231 or equiv; 3 lect and 1 prob hrs per wk)
Classical theory of electric and magnetic fields making free use of vector algebra and vector calculus. Maxwell's equations for free space and material media. Wave solutions.

5025.° SPECIAL TOPICS IN ELECTRIC AND MAGNETIC FIELDS. (4 cr; prereq 5013 or 5024; 3 lect and 1 prob hrs per wk)
Special topics of interest to instructor.

5051-5052-5053.° CLASSICAL PHYSICS. (4 cr per qtr; prereq 5013 or both 5022 and 5024, or ♯, advanced calculus or ♯; 3 lect and 1 prob hrs per wk)
Classical mechanics, special theory of relativity, and classical electrodynamics. Applications of advanced mathematical techniques to these subjects.

5091. PHYSICAL ACOUSTICS OF MUSIC. (5 cr [no grad cr in physics]; prereq 1 yr high school algebra and upper division or grad standing in music or music education, or equiv background in music theory and practice as certified by inst; 3 lect, 1 discussion, and 3 lab hrs per wk)
Principles of physics and acoustics as they relate to musical sounds, musical instruments, and the electronic production and reproduction of musical sounds. Laboratory work an integral part of course.

5101-5102.° INTRODUCTION TO QUANTUM MECHANICS. (4 cr per qtr; prereq 3512; 3 lect and 1 prob hrs per wk)
The mathematical techniques of quantum mechanics. Wave packets; Schrodinger equation, angular momentum; radial equation; spin; perturbation theory; collision theory.

5120.° EXPERIMENTAL PHYSICS. (4 cr [may be repeated for cr]; prereq 3513, △; 6 lab hrs per wk)
Techniques and methods used in physics research laboratories. Experiments in high vacuum, mass spectroscopy, solid state, atomic, and nuclear physics.

5151-5152-5153.° QUANTUM MECHANICS. (4 cr per qtr; prereq 5102 or equiv, advanced calculus or ♯; 3 lect and 1 prob hrs per wk)
Development from first principles. Schrodinger equation, angular momentum, scattering, matrix representations, spin, approximation methods, interaction with the electromagnetic field, systems of identical particles, applications to atomic systems.

5201-5202.° THERMODYNAMICS, STATISTICAL MECHANICS. (4 cr per qtr; prereq 3501 or 3511, Math 3211 or 3411 or equiv; 3 lect and 1 prob hrs per wk)
Formulation of basic laws of thermodynamics concerning temperature, energy, and entropy; application to simple systems. Transport phenomena; principles of statistical mechanics.

5203.* INTRODUCTION TO SOLID STATE PHYSICS. (4 cr; prereq 5202, or ‡; 3 lect and 1 prob hrs per wk)
Structure; thermal, magnetic, and dielectric and electronic properties of crystalline solids.

5231-5232-5233.* INTRODUCTION TO SOLID STATE PHYSICS. (4 cr per qtr; for grad and advanced undergrad students in physics, science, and engineering; 4 lect hrs per wk)
5231: Crystal structure and binding; diffraction; phonons; thermal and dielectric properties of insulators. 5232: Free-electron model; band structure; semiconductors; diamagnetism; paramagnetism; ferromagnetism and antiferromagnetism. 5233: Optical phenomena, lasers; superconductivity; surface properties; ferroelectricity.

5301.* INTRODUCTION TO NUCLEAR PHYSICS. (4 cr; prereq 5102 or equiv; 3 lect and 1 prob hrs per wk)
Static properties and dynamic processes of atomic nuclei. Survey of field for nonspecialist, and first course for those intending to specialize in nuclear physics.

5351.* EXPERIMENTAL PARTICLE PHYSICS. (4 cr; prereq 3513; 3 lect hrs per wk and field trips)
Interactions of particles and photons with matter and radiation. Detectors for particles and photons used in elementary particle, nuclear, and cosmic ray physics.

5401.* INTRODUCTION TO CONTEMPORARY PROBLEMS IN COSMIC RAY AND SPACE PHYSICS. (4 cr; primarily for students specializing in other branches of physics; prereq ‡; offered alt yrs)
Cosmic rays, their characteristics, their motion in the interplanetary and interstellar medium. X-rays and radio astronomy.

5441.* INTRODUCTORY METEOROLOGY. (4 or 5 cr; prereq 1291 and Math 3231 or ‡; 4 class meetings and 1 optional lab per wk)
Physical description of atmospheric phenomena, primarily on a large scale. The theory and practice of meteorological observation, weather prediction, and interpretation of climatological data.

5442.* DYNAMIC METEOROLOGY. (4 cr; prereq 5441 or ‡)
Fluid dynamics of large-scale atmospheric flow. Discussion of mathematical models of simple flow processes; modeling for numerical prediction, energetics, planetary boundary flow.

5451.* CLOUD PHYSICS. (4 cr; prereq Math 3211 or equiv, 1 yr general physics; 3 lect and 1 lab hrs per wk)
Composition of the atmosphere, past, present, and future. Thermodynamics of atmosphere with condensable water. Properties and growth of drops and ice crystals. Particles in the atmosphere. Open laboratory.

5452.* CLOUD SYSTEMS. (4 cr; prereq Math 3211 or equiv, 1 yr general physics; 3 lect and 1 lab hrs per wk)
Circulation, energy balance of atmosphere. Radar techniques for analyzing cloud systems. Cloud structure and motion. Open laboratory.

5453.* ELECTRICAL PROPERTIES OF CLOUDS. (4 cr; prereq Math 3211 or equiv, 1 yr general physics; 3 lect and 1 lab hrs per wk)
Structure, thermodynamic and electrical properties of water and ice. Ions in the atmosphere. Generation of charge and its effects on cloud processes. Generation of lightning and properties of lightning discharges. Open laboratory.

5804.* OPTICS LABORATORY. (4 cr; prereq 3012 or 5805 or ‡; two 3-hr labs per wk)
Optics experiments: modern optics, properties of lasers, spatial filters, light modulation, microwaves, Kerr cell, holography, Faraday effect, Zeeman effect, optical pumping, etc.

5805.* CONTEMPORARY OPTICS. (4 cr; prereq 3012 or ‡; 3 lect and 1 prob hrs per wk)
Current developments in optics. Theory of lasers and their applications in holography, nonlinear optics, etc. Nonlinear optics. Optics of anisotropic media. Theory of image formation and spatial filtering. Properties of optical detectors.

5851.* ELECTRONIC MEASUREMENT. (5 cr; prereq 3011 or ‡; 3 lect and 3 lab hrs per wk)
Measurement of physical properties using electronic techniques. Energy and measurement; noise and bandwidth; processing of repetitive and random signals.

5852.* ELECTRONIC CONTROL. (5 cr; prereq 3011 or ♯; 3 lect and 3 lab hrs per wk)
Digital and analog control: digital logic; pneumatic, electromechanical, and semiconductor systems; feedback; servosystems; mixed systems.

5853.* ELECTRONIC COMPONENTS. (5 cr; prereq 3011 or ♯; 3 lect and 3 lab hrs per wk)
Electronic components, their electrical behavior, and their use in circuit design.

5923.* HISTORY OF 16TH TO 18TH-CENTURY PHYSICS. (4 cr; prereq general physics or ♯)
Internal conceptual developments in physics and astronomy from the Scientific Revolution (Copernicus, Gilbert, Galileo, Bacon, Newton, Huygens, etc.) to the end of the 18th century (Euler, Franklin, Coulomb, Laplace, etc.). The relationships of these developments to social, philosophical, and theological influences will be treated as appropriate.

5924.* HISTORY OF 19TH-CENTURY PHYSICS. (4 cr; prereq general physics or ♯)
Internal conceptual developments in physics in the 19th century (Young, Fresnel, Oersted, Ampere, Faraday, MacCullagh, Maxwell, Hertz, Lorentz; Lavoisier, Rumford, Dalton, Mayer, Joule, Helmholtz, Carnot, Clausius, Kelvin, Boltzmann, Mach, etc.). The relationships of these developments to social, philosophical, and theological influences will be treated as appropriate.

5925.* HISTORY OF 20TH-CENTURY PHYSICS. (4 cr; prereq general physics or ♯)
Internal conceptual developments in relativity (Michelson, Lorentz, Poincare, Einstein, etc.), quantum mechanics (Planck, Einstein, Rutherford, Bohr, Sommerfeld, Ehrenfest, Pauli, Millikan, Compton, Heisenberg, de Broglie, Schrodinger, Born, etc.), and nuclear physics (Chadwick, Gamow, Fermi, etc.). The relationships of these developments to social, philosophical, and theological influences will be treated as appropriate.

5950. SENIOR SEMINAR. (Cr ar; primarily for sr physics majors; prereq △)

5990. DIRECTED RESEARCH: ELEMENTARY PHYSICAL INVESTIGATION. (Cr ar; prereq 3rd yr, △)
Problems, experimental or theoretical, of special interest to students. Written reports.

FOR GRADUATE STUDENTS ONLY

8000.* SEMINAR: THEORETICAL PHYSICS

8041-8042-8043.* PRINCIPLES OF MATHEMATICAL PHYSICS

8081-8082.* GENERAL RELATIVITY

8121.* ADVANCED QUANTUM MECHANICS

8122.* RELATIVISTIC QUANTUM MECHANICS

8123.* RELATIVISTIC QUANTUM FIELD THEORY

8131.* SYMMETRY AND ITS APPLICATIONS TO PHYSICAL PROBLEMS

8161.* ATOMIC AND MOLECULAR STRUCTURE

8162.* INTRODUCTION TO PLASMA PHYSICS

8163-8164.* PLASMA PHYSICS

8165.* ADVANCED TOPICS IN PLASMA PHYSICS

8200.* SEMINAR: SOLID-STATE AND LOW-TEMPERATURE PHYSICS

8211.* EQUILIBRIUM STATISTICAL MECHANICS

8212.* TRANSPORT THEORY

8216.* MANY-BODY THEORY

8221-8222-8223.* SOLID-STATE PHYSICS

8232.* MAGNETISM

8233.* SUPERCONDUCTIVITY

8234.* TECHNIQUES OF LOW-TEMPERATURE PHYSICS

8235.* LIQUID AND SOLID HELIUM

8236.* MAGNETIC RESONANCE
8238.* ADVANCED TOPICS IN SOLID-STATE AND LOW-TEMPERATURE PHYSICS
8300.* SEMINAR: NUCLEAR PHYSICS
8311-8312-8313.* NUCLEAR PHYSICS
8321.* ADVANCED TOPICS IN NUCLEAR PHYSICS
8360.* SEMINAR: MASS SPECTROSCOPY
8370.* SEMINAR: ELEMENTARY PARTICLE PHYSICS
8371.* INTRODUCTION TO ELEMENTARY PARTICLE PHYSICS
8372-8373.* ELEMENTARY PARTICLE PHYSICS
8380.* ADVANCED TOPICS IN ELEMENTARY PARTICLE PHYSICS
8400.* SEMINAR: COSMIC-RAY AND SPACE PHYSICS
8411-8412.* COSMIC-RAY AND SPACE PHYSICS
8421-8422.* SOLAR AND MAGNETOSPHERIC PHYSICS
8440.* SEMINAR: ATMOSPHERIC PHYSICS
8445.* ADVANCED TOPICS IN ATMOSPHERIC PHYSICS
8481-8482-8483.* ASTROPHYSICS
8484.* ORIGIN AND EVOLUTION OF THE SOLAR SYSTEM
8900.* SEMINAR: HISTORY OF 20TH-CENTURY PHYSICS
8950.* SEMINAR: PROBLEMS OF PHYSICS TEACHING AND HIGHER EDUCATION
8990.* RESEARCH IN PHYSICS

V. FACULTY—INSTITUTE OF TECHNOLOGY

In the faculty listing which follows, P.E. designates registration as a Professional Engineer, and P.A. designates registration as a Professional Architect.

AEROSPACE ENGINEERING AND MECHANICS

Professor

Abraham S. Berman
Roger L. Fosdick
Helmut G. Heinrich
Philip G. Hodge, Jr.
Chih Chun Hsiao
Daniel D. Joseph
Thomas S. Lundgren
Robert Plunkett
Patarasp R. Sethna, *Head*
William H. Warner

Associate Professor

Gordon S. Beavers, *Associate Head*
John P. Moran
Eugene Stolarik
Theodore A. Wilson

Assistant Professor

Jack L. Dais
William Garrard, Jr.
Harold L. York

AGRICULTURAL ENGINEERING

Professor

Arnold Flikke, P.E., *Acting Head*
Evan Allred, P.E.
Landis L. Boyd, P.E.
Kenneth A. Jordan
Curtis L. Larson
Jesse H. Pomroy
Cletus E. Schertz
John Strait, P.E.

Assistant Professor

James Gilley
Philip R. Goodrich
R. Vance Morey
John Rosenau
David R. Thompson

ARCHITECTURE AND LANDSCAPE ARCHITECTURE

Professor

Ralph Rapson, P.A., *Head*
Robert G. Cerny, P.A.
Roger B. Martin
Valerius Michelson, P.A.
John S. Myers, P.A.
Leonard S. Parker, P.A.
Hugh Peacock, P.A.
James E. Stageberg, P.A.
Walter K. Vivrett, P.A.
George C. Winterowd, P.A.

Associate Professor

Bruce Abrahamson
Roger D. Clemence
Carl Graffunder, P.A.
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